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Do noise masks terminate target processing?

DEREK W. SCHULTZ and CHARLES W. ERIKSEN
University of Illinois, Champaign/Urbana, Illinois 61820

Much recent research in visual information processing has employed a methodology resting on the assumption that a noise mask following presentation of a target stimulus terminates processing of that target. In the absence of appropriate controls, such a methodology is viable only insofar as an erasure theory of masking is valid. However, the phenomena from which the erasure position has derived its strongest support have been subject to alternative theoretical explanations, the most general of which is that of temporal integration. The experiment reported here tested these alternatives. Twelve subjects served in a tachistoscopic study designed to determine whether the same noise field of dots could either erase a degraded target digit or facilitate target identification through temporal integration, under both forward and backward masking paradigms. This was found to be the case, and the results were interpreted as consistent with an integration theory of masking and as incompatible with an erasure conception. The results suggested that efforts to control target processing time through display of a visual noise pattern subsequent to target presentation are methodologically inadequate when devoid of some basic control operations.

Many recent studies of visual information processing (e.g., Averbach, 1963; Haber & Standing, 1968; Johnston & McClelland, 1973; Reicher, 1969; Sperling, 1963; Wheeler, 1970; Wing & Allport, 1972) have employed a methodology based upon the assumption that a "noise" field presented within about 100 msec following presentation of a visual target either erases that target or terminates its processing. The employment of such a mask has been used to determine, or to control precisely, the amount of time the target will be available for processing. Further, many authors (Averbach, 1963; Keele, 1973; Lindsey & Norman, 1972; Posner, 1973; Sperling, 1963) have constructed information processing theories and models on the basis of data obtained through methodologies critically dependent upon a termination assumption.

For the sake of psychological theory alone, it becomes crucial to determine the validity of methodologies employing noise masks to control target processing time. Since it has been demonstrated repeatedly that a subject can continue to process a target after its physical termination, much of visual information processing research would be simplified were it possible to terminate processing with a noise mask. Further, the duration of the iconic trace by which the subject's processing continues is variable and difficult to determine. Thus, if the noise mask does not terminate target processing, the experimenter is faced with the tedious and probably futile task of empirically determining how long the target was available to the subject for every trial.

The wide acceptance of the assumption that noise masks either erase or terminate target processing seems to be more dependent upon the convenience of the assumption than upon overwhelming logic or inexorable fact. On the contrary, there is considerable evidence to suggest that, in many cases at least, successive visual events occurring within a time span of as long as several hundred milliseconds are either summed or integrated into a composite much like a montage. Whether a noise mask would then stop further processing of a preceding target would depend critically upon whether the superimposition of its features upon the target would eliminate critical discriminatory detail.

Several investigators have proposed an integration acount of masking (Eriksen, 1966; Eriksen & Collins, 1967; Eriksen & Hoffman, 1963; Kahneman, 1965; Kinsbourne & Warrington, 1962). They have noted that the visual system does not show a capacity for infinitely fine temporal resolution and have noted the relation between many masking phenomena and the known characteristic of the visual system to sum or to integrate stimulation over brief temporal intervals. Moreover, they have shown that the results of masking by light flashes and noise fields, can be described in terms of integration and/or summation of the target and the mask into a composite which reduces the figure-ground contrast of the target and/or obscures its distinguishing features.

The summation accounts of masking draw upon the established fact that the visual system does not show a

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capacity for infinitely fine temporal resolution. Bloch's law is perhaps the best known manifestation of the summating characteristic. While Bloch's law deals with perceived brightness, Kahneman and his colleagues (Kahneman, 1964; Kahneman & Norman, 1964; Kahneman, Norman, & Kubovy, 1967) have shown that time-intensity reciprocity holds for form perception as well. Further, this research demonstrated that the critical duration ($I \times T = C$) over which summation occurs is appreciably longer than that obtained for brightness—as much as 300 msec as opposed to less than 100 msec for brightness (cf. Bruder & Kietzman, 1973).

Neither brightness summation nor form summation over time depend upon continuous stimulation during the critical duration or interval. Experiments by Blackwell (1963), Davy (1952), and Lichtenstein and Boucher (1960) have shown that perceived brightness is determined by the amount of energy that occurs within the critical duration, regardless of whether the energy is presented continuously or in intermittent pulses. Similarly, Schurman, Eriksen, and Rohrbaugh (1968) have shown that summation occurs in form perception when the stimulation is presented in pulses separated by dark intervals, though here the summation is not as complete as that obtained by Kahneman and his associates. Nonetheless, Schurman et al. (1968) found, for example, that two 10-msec stimulations of a form separated by a 54-msec dark interval resulted in an appreciably higher identification accuracy than could be accounted for on the basis of two independent chances to perceive.

The relevance of form and brightness summation to masking can be seen most clearly if we compare one of the experimental arrangements of Schurman et al. (1968) and a comparable masking paradigm. In the integration paradigm, a form such as a capital letter is presented for 10 msec, followed by a blank 54-msec interval, and then another 10-msec presentation of the form. A masking paradigm, then, would be essentially the same: a presentation of a capital letter for 10 msec, a 54-msec blank interval, and then a 10-msec presentation of a black ring circumscribing the area where the form had appeared. The experimental arrangements are identical except for the nature of the second stimulus. In the first paradigm, there is evidence of integration or of summation: Performance is appreciably above the level to be expected from two independent chances to perceive. Why is integration not expected in the second experiment? If the second stimulation produces erasure in the second paradigm, why does it not do so in the first? An erasure theory of masking seems unable to account for the differential outcome of results under essentially identical paradigms, without resorting to post hoc assumptions.

Instead of predicting that a second stimulus will erase a preceding stimulus, integration theory would predict that the outcome of the two stimulations would depend upon the particular nature of the integrated composite from the two stimuli. Thus, if the two stimuli consisted of a repetition of the same stimulus on the same retinal area, integration would predict improved identification from the summation of energy, or, if beyond the summation interval, a prolongation of stimulus availability by "recharging" the decaying iconic representation from the first stimulation. If the second stimulus were a noise mask consisting of bits and fragments of letters or dots scattered throughout the tachistoscopic field, impaired recognition of a preceding target letter would be predicted, since the superimposition of the patterns of fragments or dots would obscure distinguishing features of the target. Further, integration theory would predict that two stimuli, each alone essentially a meaningless collection of light and dark patches, could be perceived as meaningful objects or patterns if presented within close temporal contiguity.

Eriksen and Collins (1967, 1968) tested the latter prediction from integration theory. Subjects viewed two brief stimulus patterns which were presented simultaneously or were separated by short interstimulus intervals (ISIs). Each of the two stimuli alone appeared to be a random array of dots. Only when the two stimuli were superimposed did the arrangement of dots produce a clearly apparent trigram. Subjects were able to identify the trigram with nearly perfect accuracy when the two stimuli were presented simultaneously and performance decreased only slightly when an ISI of 25 msec was introduced. In fact, performance did not become asymptotic until ISIs as long as 200-300 msec intervened between the two dot patterns. Using similar stimuli, Cohene and Bechtoldt (1974), Hogben and DiLollo (1974), and Pollack (1973) obtained comparable results. Rohrbaugh and Eriksen (1975) replicated this effect using brief exposures of two matrices of illuminated squares. The matrices were identical except for spatial displacement, which was arranged so that they could be superimposed to yield either horizontal or vertical stripes. They found that choice reaction times to the composite stripe orientation indicated integration over an ISI range in excess of 224 msec.

While the above evidence would seem to cast strong doubts on the adequacy of an erasure theory of masking, an ideal experimental task to choose between integration and erasure theories would be one in which essentially the same masking stimulus could be shown either to improve or to impair target identification. The present experiment provides such a demonstration.

The experiment used a number of noise masks consisting of a pseudorandom arrangement of black dots on a white field. All the masks were highly similar to each other, differing only in that a small fraction of the dots were displaced by a mirror-vision inversion on the vertical midline, or on both vertical and horizontal midlines of the stimulus. In the enhancement condition, a small number of dots were placed in the mask so that when the target and mask were superimposed the dots enhanced details of the target. In the confusion condition, a mirror-inversion of a small number of dots tended to create a configuration so that the target vaguely resembled a different target when target and mask were superimposed. In the noise condition, these few dots were removed to provide a control for the effects of dot displacement. Finally, to provide a performance baseline, a no-mask condition was employed in which the target was presented without a masking pattern.

Predictions for these experimental conditions follow directly from either masking theory. The erasure theory would predict impaired target identification under not only the noise condition, but also the enhancement and confusion conditions. Further, it would predict much more extensive masking under a backward masking paradigm than under a forward masking paradigm: If a second stimulus erases the preceding stimulus, then presentation of the target after the mask (forward paradigm) should not impair target identification.

Integration theory, on the other hand, makes a number of different predictions, depending upon the experimental conditions. First, integration theory would predict little difference between forward and backward masking paradigms. Second, target identification should be better at short ISIs under the enhancement condition than under the other conditions. Performance (as ISI increases) in this condition should *decrease* to the level of that obtained for the no-mask condition. Under the noise condition, performance should be poorer than when the subject sees the target alone, since embedding the target in a noise field will degrade the target. However, performance here should *increase* to the no-mask condition as ISI increases. Performance under the confusion condition should be worst of all; not only is the target degraded by being embedded in the noise field, but the displacement of certain dots so as to make that target confusable with another target should increase the number of errors over that obtained in the noise condition.

METHOD

Subjects

Twelve University of Illinois graduate and undergraduate students, three male, served as paid volunteers. All had normal or corrected-to-normal vision and extensive prior experience with tachistoscopic displays.

Apparatus and Stimuli

Trials were conducted on a Scientific Prototype Model GA three-field tachistoscope, modified with Sylvania F4T5/CWX fluorescent lamps. Luminances in the fields were equated at 34.6 c/m^2 as measured by a Spectra Spot Photometer. Trials were initiated at the subject's discretion by the subject's pressing a hand microswitch following the experimenter's signal, "ready."

The four stimulus targets ("2," "5," "6," and "9") are shown in Figure 1. Each target subtended .855 deg of visual angle in height and .520 deg of visual angle in width at the 50-in. viewing distance. They were constructed from 1/16-in. Paratipe dots (#55068) following a 7 x 11 matrix and were placed on clear vinyl cards. As is readily apparent, the stimulus targets can be grouped into two pairs on the basis of geometric rotations: The "2" and "5" are mirror images of each other, and the "6" and "9" are related by 180-deg rotations on both the horizontal and vertical midlines. Importantly, the target patterns were degraded by dropping corresponding dot segments from each target-rotation pair. For example, the two segments removed to degrade the "2" are in the mirror-image positions of those segments removed to degrade the target "5." A similar relation can be observed between the segments dropped from the "6" and those dropped from the "9."

The four degraded stimulus targets were crossed with the four stimulus conditions in the experiment: noise, enhancement, confusion, and no-mask. Following the recommendation by Haber (1970), the noise mask consisted of dots of the same type as those used to construct the target stimuli. Noise dots were placed in an apparently random fashion, with the constraint that no dot in the noise pattern could overlap any dot in any target stimulus. Four enhancement masks were constructed (one for each target stimulus) by duplicating the noise pattern and adding the appropriate dot segments that were dropped to initially degrade that target.

The confusion condition entailed construction of four target-specific masks in a manner similar to that of the enhancement condition. In this case, however, the two dot segments added to the mask to construct the confusion mask for a specific target were those dropped from the rotational complement of that target. For example, the dot segments added to the noise pattern to construct the confusion mask for the target "2" were in the same position as those dropped from the target "5" to initially degrade it. Mask patterns for the "5," "6," and "9" were constructed in the same manner. This procedure created stimulus configurations in the confusion condition which, when target and mask were presented simultaneously, resulted in pairwise stimulus confusions (i.e., calling the target "2" a "5," and vice versa; calling the "6" a "9," and vice versa). Finally, the no-mask control condition merely required that a clear vinyl card be presented to balance luminances across all four stimulus conditions.

For any trial, the target was always presented in the first tachistoscopic field with a white vinyl backing card. Moreover, to render the stimulus field more homogeneous, and to further impair recognition of the degraded target, a dense field of dots (of the same type as those employed in constructing all stimulus patterns) surrounded the area where the target would appear and was always placed in the first channel with the target stimulus. The mask (or clear card in the case of the no-mask condition) for the various stimulus conditions always appeared in the second tachistoscopic field, with a white vinyl backing card and a clear vinyl card to balance the luminance filtered by the dense dot field surrounding the target in the first channel. Finally, an adaptation field with a fixation cross subtending .2 deg of visual angle and centered on the target position remained on, unless another field was activated. To maintain constant luminance in all fields, the fixation cross was presented with two clear vinyl cards in front of it.

Procedure

Each subject served in one practice session, followed by two experimental sessions. Each session began with several minutes of dark adaptation, during which the experimenter read to the subject the instructions appropriate to that session. The practice session was designed to: (1) acquaint the subject with brief tachistoscopic exposures, (2) familiarize the subject with a recognition task involving degraded numerals constructed from dots, and (3) adjust the subject's stimulus duration on the no-mask condition to a level corresponding to roughly 75% accuracy.

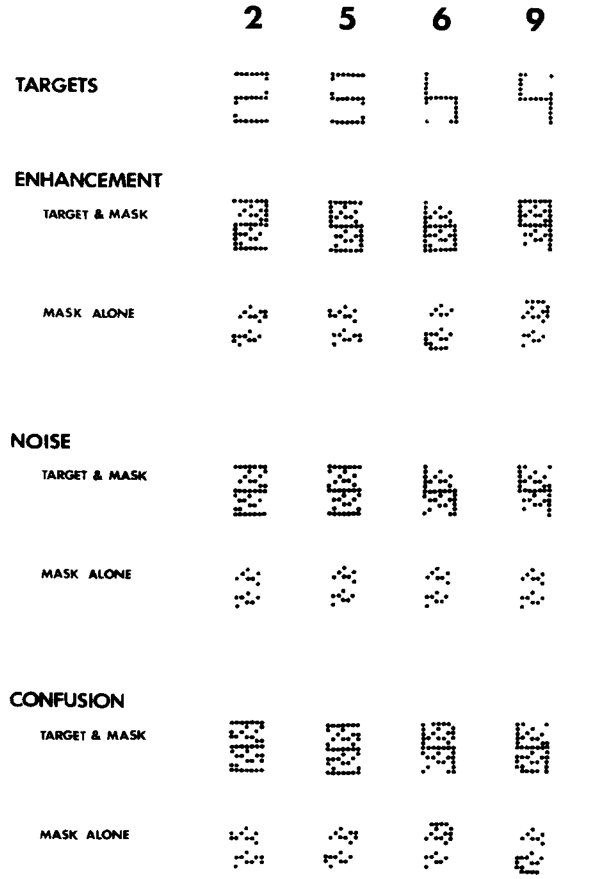

Figure 1. Representative stimuli under the four masking conditions.

Each experimental session began with ten warm-up trials chosen so that the trials were the last ten encountered by the subject in the first block of that session, in reverse order. Each session was run under either a forward masking paradigm (mask preceding the target pattern) or a backward masking paradigm (target preceding the mask pattern). The subject was informed of the paradigm to be employed at the outset of each session. Order of paradigms was completely counterbalanced across subjects.

An experimental session consisted of four blocks of 48 trials each, one block at each ISI (0, 50, 100, and 150 msec) between the two stimulus patterns. Block order was completely counterbalanced across subjects. Each block entailed three trials on each of the 16 possible stimulus patterns ("2," "5," "6," or "9" as target crossed with the four conditions). Across subjects, the experiment provided 144 observations per cell of the design.

As mentioned previously, stimulus duration of the target pattern was determined for each subject during the practice session. The mean duration was 8 msec (range, 5-10 msec). The second field (containing the mask or a blank card) was matched in duration to the target field. Trials were conducted binocularly, and feedback in terms of number of correct recognitions followed each block.

RESULTS

Percent correct identifications were analyzed in a four-way mixed model analysis of variance (forward or backward masking by ISI by stimulus condition by subjects). All main effects were highly significant ($p < .001$). The only interaction to reach significance was that between ISI and stimulus condition ($p < .001$); all interactions involving the forward or backward masking paradigm failed to approach significance.

Figure 2a presents the data obtained when averaged across both forward and backward masking paradigms, with percent correct target identifications under each stimulus condition plotted against ISI. Data under the forward and backward masking paradigms are presented separately in Figures 2b and 2c, respectively.

To determine the extent to which facilitation of target identification occurred in the enhancement condition, several subsequent analyses were conducted. The first of these entailed a separate analysis of variance on the data under only the enhancement and no-mask conditions. Facilitation in the enhancement condition

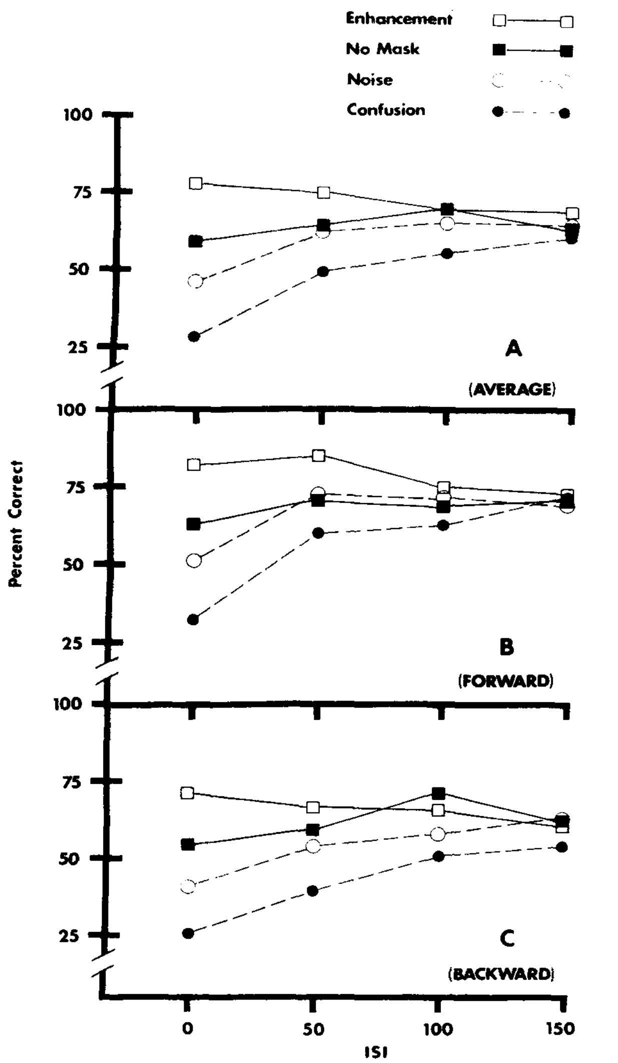

Figure 2. Mean accuracy under each masking condition as a function of target-mask interstimulus interval.

would result in significant interaction between these conditions. Main effects of masking paradigm and stimulus condition reached significance ($p < .01$) in this analysis, though the main effect of ISI did not. However, the interaction of ISI by Stimulus Condition was significant ($p < .0025$) due to facilitation of performance under the enhancement condition at short ISIs.

To assess the main effect of ISI under the enhancement condition separately, a third analysis of variance (masking paradigm by ISI by subjects) was conducted on these data alone. Again, all main effects were significant, though the interaction of paradigm and ISI did not approach significance. Moreover, a linear trend analysis on the data under the enhancement condition revealed a highly significant linear component ($F = 83.87$, $df = 1{,}99$, $p < .0001$), with no significant departure from linearity ($F = 1.70$, $df = 3{,}99$, $p > .10$). In conjunction with this linear performance decline under the enhancement condition, the significance of the main effect of ISI in this analysis is seen as reflecting a significant decrease in temporal integration over this ISI range.

The integration theory of masking predicted that the confusion condition would result in the poorest target identification accuracy because, in that condition, a temporally integrated target-mask montage would resemble an incorrect target, thereby misleading the subject into an error. Thus, a final analysis was conducted to determine the extent to which pairwise confusions (of four confusion types, i.e., calling the target "2" a "5," and vice versa; calling the target "6" a "9," and vice versa) occurred under each stimulus condition. Tabulation of the number of all types of errors (including pairwise confusion errors) for each subject under each stimulus condition and every level of ISI permitted the computation of the ratio of confusion errors to total errors for each of the four pairwise confusion types. This ratio was then treated as the dependent variable in a three-way analysis of variance (confusion type by stimulus conditions by subjects). Since such confusions should predominate at low levels of ISI, this analysis was conducted with data pooled across the first two ISI levels (0 and 50 msec).

The main effect of stimulus conditions was highly significant ($p < .001$). Moreover, the ratio of confusion errors to total errors was ranked across conditions as would be predicted from integration theory: The enhancement condition displayed relatively few confusions (26.40%), the no-mask condition almost twice as many (50.35%), the proportion of confusions under the noise condition was nearly equal to that under the no-mask condition (55.23%), and the ratio of confusions to total errors was greatest under the confusion condition (64.60%).

DISCUSSION

The results lend strong support to an integration theory of masking and provide no support for an erasure position. Primarily, the similarity of data under forward and backward masking paradigms, predicted from integration, was evident. Moreover, the convergent fan among stimulus conditions across ISIs predicted from the integration theory was observed: Target recognition was facilitated under the enhancement condition and was inhibited under both the noise and the confusion conditions, significantly more so under the latter. The confusion condition also displayed an "erasure-like" effect: The data under that condition originated at chance accuracy and increased monotonically with increasing ISI to asymptote at the target baseline. It is clear from the data, however, that the masking was not due to erasure. First, the configuration of data under all experimental conditions and paradigms appears consistent only with an integration theory of masking. Moreover, were the mask pattern erasing the target, errors in that condition should have been equally distributed among all four alternative responses. Results of the confusion analysis, however, clearly demonstrate that the greatest proportion of errors under the mask conditions were confusions. In summary, support for an integration theory of masking is impressive.

At this point, one might question whether an erasure process ever occurs in visual masking, or whether so-called erasure effects are not more parsimoniously ascribed to: (1) integration through energy summation when the successive stimulations fall within the critical duration or summation interval; or (2) integration due to superimposition on the sensory register of the new stimulation (mask) upon the decaying trace or icon of the previous stimulus (target). The evidence that integration occurs seems incontrovertible, and, if an erasure process is to remain viable, a set of operations must be specified that would distinguish it from integration.

Several recent papers (Bongartz & Scheerer, 1976; Scheerer, 1973; Spencer & Shuntich, 1970; Turvey, 1973) have recognized the role of integration in masking, but have maintained a dual-process theory in which interruption (erasure) occurs under certain circumstances. Integration is limited to stimulus onset asynchronies (SOAs) of 150 msec or less (Scheerer, 1973; Spencer & Shuntich, 1970), while interruption is ascribed to masking effects that occur at longer SOAs. In these experiments, multielement displays are employed as targets, and the subject must process an indicator or cue (presented with a target display) in order to know what letter to report. It has been shown in many experiments that processing an indicator or cue requires as long as 200 msec or longer (Averbach & Coriell, 1961; Colegate, Hoffman, & Eriksen, 1973; Eriksen & Collins, 1967), during which time the display icon fades (Eriksen & Collins, 1968). Thus, if the mask is presented before the subject has located and encoded the target element, the target's iconic representation is degraded further by the superimposition of the strong undecayed representation of the mask. Eriksen and Rohrbaugh (1970) have presented at length an integration account of masking with multiletter displays, and their experimental results conform quite closely with their theoretical predictions. In fact, the results obtained by Spencer and Shuntich (1970) can be viewed as an extensive replication of Eriksen and Rohrbaugh (1970), in which the results conform with an integration account in fine detail. There can be little doubt that the superimposition of the representation of the mask upon the decayed trace of the target will *interfere* with processing of a target, but it is gratuitous to conclude that target processing is *interrupted* without converging operations.

The most conservative conclusion permitted from the data is that presentation of a noise field to control the processing time of a preceding target is a misleading, if not totally inadequate, procedure in the absence of additional control conditions as Coltheart and Arthur (1972) have pointed out. The present data strongly suggest that a noise field neither erases a preceding target nor terminates its processing; the two patterns merge through temporal integration to form a target-mask montage. Certainly, it is possible to construct a noise field so as to render undecipherable the target preceding it. However, a control condition entailing simultaneous presentation of the target and mask is crucial in assessing the effectiveness of the noise field. But, even if target identification falls to chance under a simultaneous target-mask control condition, this is not necessarily a guarantee that the target will be undecipherable when a 50-msec target-mask onset asynchrony is employed. This caveat is easily justified. It seems unlikely that a visual stimulus is processed instantaneously and all at once: More plausibly, processing occurs in stages. Perhaps a figure-ground differentiation occurs first, and several gross differentiations occur later. If an interval of 50-100 msec is allowed for this early processing to occur before a mask is presented, it is then possible that initiation of the processing steps would permit some deciphering of the target through what would otherwise be an obliterating mask montage. In any case, the present data urge that research results critically dependent on processing-termination or erasure assumptions be examined with extreme caution. Just as several tones combine to form a chord, two visual stimuli presented in temporal contiguity will also merge.

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