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AN ANALYSIS OF THE "RETROACTIVE
CONTOUR ENHANCEMENT" EFFECT***

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Standing and Dodwell (1972) reported that a contoured target stimulus which is only poorly identified when exposed briefly against a steady background field can be identified accurately if the field is terminated shortly after target offset. This observation was confirmed and, in addition, it was shown that target identification is enhanced when the field is initiated shortly before target onset. Furthermore, it was demonstrated that a continuous background field is not essential for either effect. It was argued that these "retroactive" and "proactive" enhancements of target identification were due to a complex interaction among forward, backward, and simultaneous masking.

Introduction

A target letter which is at or below recognition threshold when exposed briefly on a steady homogeneous or heterogeneous background field can become fully visible if the field terminates within about 100 ms of the target. This recent discovery of Standing and Dodwell (1972), which they have named Retroactive Contour Enhancement (RCE), suggested to them a visual storage of subliminal stimuli localized at a very early stage in the flow of the visual information.

The present paper examines the question of whether Standing and Dodwell's RCE phenomenon was the result of a storage process, as they have argued, or the result of some other kind of operation in the visual system.

Experiment I

The first experiment sought to replicate the basic finding of the Standing and Dodwell paper.

Method

Subjects

The subjects were four Yale University undergraduates who were paid \$2.00 per h for their services. All four subjects had normal or corrected-to-normal vision and all four were unfamiliar with tachistoscopic viewing.

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Apparatus and stimulus materials

The same apparatus and the same materials were used for all four experiments reported. The stimuli were presented by means of a three-channel tachistoscope (Scientific Prototype Model GB) with automatic slide changers. The viewing distance was 15 in. and the field of the tachistoscope subtended 3.5° vertically and 6.5° horizontally.

The target stimuli were a set of 100 trigrams constructed from the set of consonants with the restriction that no consonant was repeated within a trigram. The black letters on a white surround subtended 0.67° vertically and, on the average, 0.36° horizontally. The thickness of the letter parts subtended 0.13° visual angle, and the average separation between adjacent letters was 0.40° . The letters were arrayed horizontally with the middle letter positioned at the center of the field. The background field, or mask, was a random noise field, 3.5° vertical by 6.5° horizontal, used in previous experiments (see Turvey, 1973, Fig. 2). The random noise luminance was set at 0.6 ft lm as measured by a SEI photometer.

Procedure

There were two durations of the random noise mask, 700 and 1000 ms (both had been used in the Standing and Dodwell experiments). Five intervals, 500, 600, 625, 650, and 675 ms, were used between onset of the mask and onset of the target stimulus. The duration of the target stimulus was 20 ms. Therefore, at the longest onset-onset interval of 675 ms the 700-ms mask terminated 5 ms after target offset and the 1000-ms mask terminated 305 ms after target offset. The mask was superimposed on a pre-adaptation field with a centrally-located fixation point. The luminance of this field was 0.02 ft lm. The relation between the stimuli in the two conditions is shown in Figure 1.

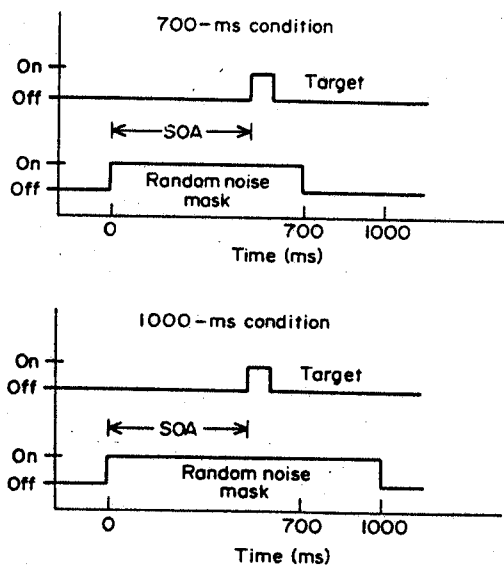


FIGURE 1. Temporal relation between random noise mask and target stimuli in the 700-ms and 1000-ms conditions of Experiment I.

Prior to testing each subject, the appropriate level of target stimulus luminance was determined so that the subject could identify an average 1.5 consonants in a trigram display exposed for 20 ms against a steady random noise background. The luminance value so determined was the target stimulus luminance used for the experiment. The average target luminance was 3.2 ft lm.

Each subject was given 12 blocks of 20 trials, six with the random noise exposed for 700 ms and six with the random noise exposed for 100 ms. Within a block the onset-onset times, or stimulus onset asynchronies (SOAs), were randomized, with the restriction that each SOA occurred four times. The subjects alternated between the random noise exposures of 700 and 1000 ms across the 12 blocks with two subjects beginning with the shorter duration and two with the longer. The consonant trigram changed with each trial, and the subjects were scored for the number of consonants correctly identified. All stimuli were presented monocularly to the right eye.

Results and discussion

The function relating the proportion of consonants correctly reported to SOA for both exposure durations of the random noise is given in Figure 2.

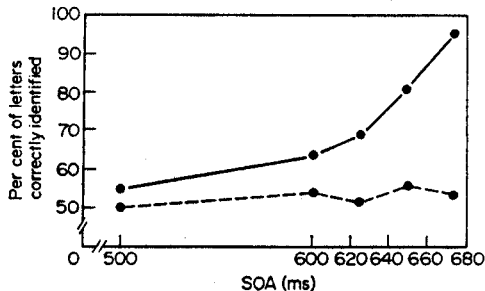


FIGURE 2. Relation between per cent correct identification and SOA with mask duration as the curve parameter in Experiment I. Mask duration 700 ms, ●—●; mask duration 1000 ms, ●---●.

A Treatment (random noise duration) \times Treatment (SOA) \times Subjects analysis of variance yielded a significant effect of noise duration ($F = 74.87$, $df = 1, 3$, $P < 0.005$), a significant effect of SOA ($F = 23.17$, $df = 4, 12$, $P < 0.001$) and a significant interaction between random noise duration and SOA ($F = 9.57$, $df = 4, 12$, $P < 0.005$).

The present experiment corroborates the main finding of the Standing and Dodwell experiments: the identification of a target stimulus increases when the background field on which the target stimulus is exposed terminates shortly after target-stimulus offset. In Standing and Dodwell's experiments the target stimuli consisted of one letter (S or L) in a forced-choice task, while the present experiment required identification of consonants presented in trigram strings. The implication is that the phenomenon is quite robust.

The only difference between the data of Standing and Dodwell and those presented here is that the increase in identification with increasing SOA in the 700-ms condition was more gradual in the present experiment. The source of this difference probably lies in the difference between the stimuli and response measures used in the two experiments.

Experiment II

The second experiment sought to determine whether the result of Experiment I could be obtained within a smaller range of mask exposures.

Method

The experiment was conducted in two parts and the apparatus and stimuli for both parts were the same as used in Experiment I. Both parts of the experiment used random noise exposures of 100 and 200 ms and a target exposure of 5 ms. The luminance of the random noise was set at 0.32 ft lm for both mask durations and for both parts of the experiment. The stimuli were presented monocularly to the right eye.

Prior to testing of subjects in both parts 1 and 2, the target luminance was determined at which approximately one item could be identified against a steady mask background. The target stimuli were then presented to each subject at this luminance for the course of the experiment. The average target luminance for the four subjects was 2.5 ft lm.

Part 1

For each of the two mask exposures of 100 and 200 ms duration the target stimuli were superimposed on the mask field at SOAs of 10, 25, 50, 75, and 90 ms. The presentation of the mask exposure duration and SOA combinations followed the same pattern as described in Experiment I. However, only six blocks of 20 trials were used in the present situation, three for each mask duration. As before, SOAs were randomized within a block with each SOA occurring four times. Two of the authors were the subjects for this part of the experiment.

Part 2

The second part of the experiment differed from the first in that five additional SOAs of 110, 130, 150, 175, and 190 ms were examined at the mask exposure of 200 ms. The two subjects for this part of the experiment were Yale University undergraduates who had never participated in a tachoscopic experiment before and who were paid for their services. Both subjects received nine blocks of 20 trials; three blocks with the mask at 100 ms, three with the mask at 200 ms and SOAs less than 100 ms, and three blocks with the mask at 200 ms and SOAs greater than 100 ms. The order of the three blocks was partly counter-balanced across the two subjects and within a block SOAs were randomized with the restriction that each SOA was examined four times.

Results and discussion

The averaged data of the two subjects in part 1 are given in Figure 3 and those of part 2 are given in Figure 4. Inspection of both figures reveals that the functions relating identification performance to SOA are nonmonotonic for the 100 ms mask exposure of parts 1 and 2 and for the 200 ms exposure of part 2. Thus, superimposing the target on to the mask background in close temporal proximity to *either* mask onset or mask offset led to enhancement in letter identification. In short, there was both proactive and retroactive facilitation and this U-shaped relation between target perceptibility and temporal location in the mask brings into question the memory interpretation of RCE proposed by Standing and Dodwell. According to that interpretation traces of the target and mask persist beyond their exposures, and, presumably, these perceptual traces decay with time. It is assumed that the target trace is the more durable of the two, either because the target is of greater intensity or because the target, unlike the mask, is contoured. In any event, if the mask offsets soon after the target exposure the mask trace will terminate before the target trace; consequently, the target trace may be accessed and the contour information recovered. On the other hand, if the mask offsets well beyond the target exposure, the mask or its perceptual trace may persist beyond the useful life of the target trace. Under these conditions recovery of the target would be impossible.

The fundamental difficulty with the persisting trace or visual storage hypothesis is that it must predict, by necessity, a positively monotonic relation between target perception and SOA—in contrast to the U-shaped relation obtained in the present experiment. On the storage hypothesis the earlier the occurrence of a target during the mask exposure the weaker must be the trace of that target at mask offset. Quite obviously the storage hypothesis does not predict *proactive* enhancement.

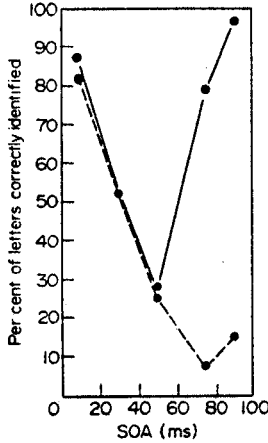


FIGURE 3. Relation between per cent correct identification and SOA with mask duration as the curve parameter in part 1, Experiment II. Mask duration 100 ms, ●—●; mask duration 200 ms, ●---●.

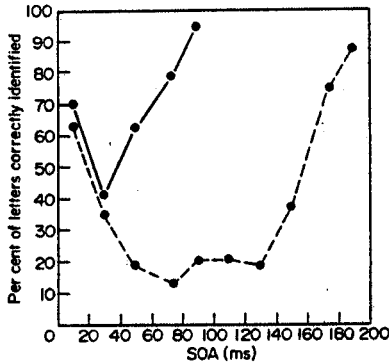


FIGURE 4. Relation between per cent correct identification and SOA with mask duration as the curve parameter in part 2, Experiment II. Mask duration 100 ms, ●—●; mask duration 200 ms, ●---●.

Two other points need to be made. First, in both Experiments I and II it was determined that the relation between the target and mask energies which produced RCE was such that the mask, at its longest durations of 1000 and 200 ms, did not significantly affect the accuracy of target identification if it either only followed the offset of the target or only preceded the onset of the target. Second, while letter identification by three of the four subjects in the present experiment was poorest in

the 100-ms mask duration condition at SOA = 50 ms, one subject's letter identification (in part 2) was lowest at SOA = 30 ms and reasonably good at SOA = 50 ms. This subject variability accounts in part for the different minima observable in the 100 ms mask functions of Figures 3 and 4.

Experiment III

The third experiment was similar to Experiment II, with one major difference. Instead of overlapping the target and mask fields temporally, the mask was terminated at target onset and continued from target offset. In other words, the target was inserted into a temporal "hole" in the mask, with the duration of this hole equal to the duration of the target. This was done to assess whether an uninterrupted presentation of the mask was essential to the proactive and retroactive facilitation effects demonstrated in Experiment II. A positive demonstration would argue that the paradigm used by Standing and Dodwell does not differ appreciably from the more common masking paradigm used to investigate interference between temporally discrete events.

Method

Two paid, tachistoscopically naive, Yale University undergraduates attempted to identify the trigram stimuli under conditions very much like those of Experiment II, part 2. The general procedure was to present a target for 10 ms preceded and followed by random noise. Two identical random noise fields were presented on two separate channels of the tachistoscope. In this experiment, therefore, there was no fixation field since all three channels of the tachistoscope were used for the random noise/target/random noise sequence. The total duration of random noise/target/random noise was either 100 or 200 ms. In the 100-ms condition the target stimulus was presented at the following SOAs: 10, 30, 50, 75, and 90 ms, where the SOA was measured from the onset of the first exposure of the random noise. In the 200 ms condition the target was presented at five additional SOAs of 110, 130, 150, 175, and 190 ms. Since the random noise mask was off for the duration of the target the total time the mask was exposed was 90 ms in the 100-ms condition and 190 ms in the 200-ms condition.

Both subjects received nine blocks of 20 trials in the fashion described in part 2 of Experiment II. Prior to the experiment the target luminance was determined by an identification accuracy of a little less than one consonant per trigram exposure when the target was superimposed upon the continuous mask. This luminance was 4.0 ft lm for both subjects. The luminance of both random noise fields was 0.32 ft lm and the stimuli were presented to the right eye.

Results and discussion

The averaged data for the two subjects are plotted in Figure 5. Comparison of Figure 5 with Figure 4 shows that the functions relating SOA to consonant-identification for the 100- and 200-ms conditions of the present experiment are identical in form to those of Experiment II. The conclusion we draw from this is that a continuous mask is essential neither for the RCE effect nor for the proactive facilitation demonstrated in Experiment II.

For the luminance levels used in the present experiment it was determined that with the mask only preceding or only following the target, impairment in the identification of the target was minimal. This was true for both the shortest

(10 ms) and the longest (190 ms) exposures examined. Uttal (1969) has recently reported an experiment which showed that a leading mask and a lagging mask which failed at a certain interval to impair target identification when presented separately nevertheless significantly reduced target identification when presented in combination. Uttal (1969, 1971) and Walsh (1971) have speculated that the elevated masking evident in Uttal's (1969) combined forward and backward masking situation may have resulted from the summation of "latent" masking effects which in themselves were inadequate to affect target recognition.

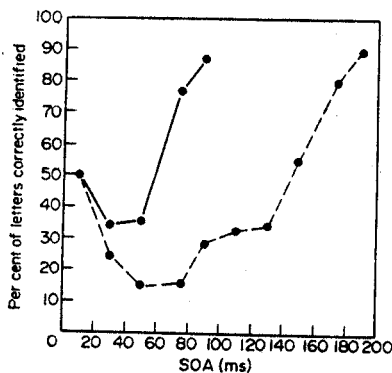


FIGURE 5. Relation between per cent correct identification and SOA with total mask/target/mask time as the curve parameter in Experiment III. Mask duration 100 ms, ●—●; mask duration 200 ms, ●---●.

If target perception in the present experiment was determined by the joint effects of "latent" forward and backward masking, then we can argue that the systematic, nonmonotonic changes in target perception as a function of SOA were the result of systematic changes in the differential masking influences of the forward and backward exposures of the random noise. We should recall at this point that in the present experiment SOA was defined as the interval elapsing between the onset of the first exposure of the random noise and the onset of the target. Therefore, since mask/target/mask time was held constant within a condition, increasing SOA was equivalent to increasing the duration of the forward mask and to decreasing the duration of the backward mask.

Within limits, an essential determinant of monoptic masking is the energy relation between the stimuli, and in the view of a recent discussion of masking (Turvey, 1973) when two stimuli are competing for common peripheral networks, the stimulus of greater energy tends to have the advantage. In the present experiment the target was more intense than the mask, 4.0 ft lm compared to 0.32 ft lm, and therefore, for equivalent exposure durations the target was of greater energy than the mask, where energy is defined as: duration \times luminance. Thus, at brief SOAs in the present experiment the target probably impaired the leading random noise more than the leading random noise impaired the target. Therefore, we suspect that at these brief SOAs forward masking effects were minimal, and the weight of the masking action was on the lagging exposure of the random noise.

This, we may recall, was not an effective masker when presented in the absence of the leading exposure. However, at longer SOAs, e.g. 60-70 ms, the forward random noise, because of its increased energy, was a more pronounced forward masker and could more effectively interact with the lagging random noise to impede target perception. In short, the transition from brief to moderately long SOAs in the present experiment was accompanied by an increase in the effectiveness of the forward masker. In the presence of the backward mask this resulted in the decreasing perceptibility of the target as a function of SOA. This accounts for the "proactive facilitation" effect evident in the present data, and we can account for the RCE effect in a similar fashion.

We can assume that at the longer SOAs the duration, and therefore, the energy of the backward mask was reduced below that point at which independently it could maximally influence the target. We should bear in mind, of course, that the maximal influence of the random noise as either an independent forward or backward masker was not sufficient to impair target identification; but as Walsh (1971, p. 265) has commented; "discriminability is not equivalent to invulnerability". In any event, at the longest SOAs the backward masking action of the random noise was minimized, leaving the leading exposure of the random noise as the major source of masking. Consequently, in both conditions of the present experiment target identification increased as backward masking decreased, with increases in SOA from the middle to the longest values. This increase in target identification at the longest SOAs is RCE.

Thus, the RCE effect manifest in the present experiment may be interpreted as a change in target identification resulting from variation in the joint masking effect of leading and lagging masks. We believe that this conclusion can be generalized to the RCE effect observed in Experiments I and II of the present paper, and to the experiments of Standing and Dodwell. In those experiments the target and mask overlapped temporally, a condition which, in view of the foregoing, can be interpreted as a target/mask composite preceded and followed by a mask. At most, performance in a continuous mask situation should be poorer than performance in a comparable, interrupted mask situation in view of the additional element of latent simultaneous masking. In our view, therefore, the difference between the two situations is simply one of degree.

Experiment IV

The fourth experiment was designed to test the masking interpretation of Experiment III and thus, of the RCE effect. If target identification in Experiment III was due to the joint effect of the forward and backward mask, then varying the masking capability of either the leading or lagging exposure of random noise, or both, should affect target identification.

We have good reason to believe that in the present series of experiments the locus of the influence of the random noise mask on target stimulus perception was peripheral rather than central. It was determined that at the intensity levels used in Experiments I, II, and III, the random noise, either overlapping or not overlapping temporally with the target, could not impede target perception when it was

presented to one eye and the target stimulus was presented to the other. In addition, the random noise mask of the present series of experiments had been shown previously, over a range of conditions, to be a relatively ineffective dichoptic masker for the present set of trigram target stimuli (Turvey, 1973).

Accepting the peripheral origin of the RCE effect demonstrated in the three experiments of the present paper and, we presume, in the experiments of Standing and Dodwell, we would expect that a major determinant of peripheral masking, the energy relation between the stimuli (Turvey, 1973) is also a major determinant of RCE. In this view, what was important to the RCE effect of Experiment III was the relation between the energies of the pre- and post-target mask exposures and the target, and not the proximity of the target to mask offset. To test this hypothesis the luminance and duration of the lagging random noise exposure were varied. If energy, rather than the time before mask offset, was the important variable determining RCE, then target perceptibility should not be altered by the reciprocal interchange of mask duration and mask intensity, but it should be significantly influenced by the independent manipulation of either.

Method

Three Yale University undergraduates, naive about tachistoscopic presentation, were paid for their participation. The experiment used the target and mask stimuli of the preceding experiments.

In most respects the experimental procedure was similar to that described for Experiment III, i.e. a 10-ms target was preceded and followed by a random noise exposure. In the present experiment, however, the duration and intensity of the lagging exposure were systematically varied. The luminance of the lagging random noise was set at 3.2 ft lm and then presented at 50% (1.6 ft lm), 25% (0.8 ft lm), or 10% (0.32 ft lm) of this value. These three luminance levels of the lagging mask were combined factorially with three durations of 10, 20, and 50 ms. Each subject received six blocks of 15 trials, two blocks per mask luminance level. Within each block five trigrams were followed by a 10-ms mask exposure, five by a 20-ms mask exposure, and five by a 50-ms mask exposure, with the mask duration randomized within the 15 trials. The six blocks were balanced across the three subjects such that each luminance level appeared with equal frequency at each position in the test. Thus, each subject received all nine luminance/duration conditions with luminance level counterbalanced and duration randomized within luminance level.

Throughout the experiment the leading random noise exposure was constant at 50-ms duration and 0.32 ft lm intensity. The mask was terminated at target onset and continued from target offset. The same target luminance of 3.2 ft lm was used for the three subjects, and all stimuli were presented monoptically, to the right eye.

Results and discussion

The proportion of letters correctly reported at each luminance/duration combination is given in Table I. Inspection of the table shows that increasing either the duration or the intensity of the lagging mask decreased target perceptibility. An analysis of variance showed that both main effects of duration and of luminance were significant; $F = 42.13$, $df = 2, 4$, $P < 0.01$ and $F = 129.20$, $df = 2, 4$, $P < 0.01$, respectively. Moreover, it was obvious that the total energy (luminance \times duration) of the lagging mask was the important determinant of performance in the present experiment. First, increasing both duration and intensity resulted in a

greater impairment in target identification than increasing either independently. Second, in the three cells of Table I in which energy was held constant by the reciprocal variation of luminance and duration, i.e. $10\% \times 50$ ms, $25\% \times 20$ ms, and $50\% \times 10$ ms, target perceptibility was relatively constant. We should also note that reducing mask duration at each of the three luminance levels resulted in an improvement in target identification; thus, the RCE effect was observed at each luminance level.

TABLE I

Experiment IV: Proportion of letters correctly identified as a function of luminance and duration of lagging mask

Duration (ms)	Luminance (per cent of 3.2 ft lm)		
	(10%)	(25%)	(50%)
10	0.86	0.83	0.42
20	0.77	0.51	0.11
50	0.41	0.17	0.07

On the evidence of Experiment IV we may conclude that the enhancement in target identification that accompanied the reduction in the target offset/mask offset interval of Experiments I-III was due to the reduced energy of the mask exposure following the target rather than to the increased proximity of offsets.

More generally, we may conclude that the nonmonotonic relation between target perception and SOA evidenced in the present experiments was due to systematic changes in the joint masking effect of the preceding and succeeding exposures of the random noise.

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