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TIME COURSE OF THE SUBJECTIVE CONTRAST ENHANCEMENT FOR A SECOND STIMULUS IN SUCCESSIVELY PAIRED ABOVE-THRESHOLD TRANSIENT FORMS: PERCEPTUAL RETOUCH INSTEAD OF FORWARD MASKING

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Abstract—Subjects estimated apparent contrast of an invariant test stimulus (the letter H), exposed either after an inducing stimulus (from the set of 12 alternatives) with SOAs varying from 20 to 290 msec, or alone (a control condition). With inducing stimuli, at certain SOAs the subjective contrast of the TS was enhanced relative to single-stimulus control. This enhancement appeared as a curvilinear function of SOA with the most pronounced enhancement at SOA = 110 msec. The effect was present also if the Ss had to recognize the inducing, backward-masked stimulus (the recognition function being U-shaped). The enhancement effect increased with increase in the intensity-level of the inducer. The separate functions for the conditions of inducing letters of high and low figural similarity with TS were coinciding, thus pointing to the nonspecific nature of the obtained effect within the given spatial constraints (1 deg of the visual angle). A small forward masking effect present with SOAs $\leqslant 40$ msec was rapidly replaced by the enhancement with increase in SOA. The results are discussed in terms of the visual masking theories and the hypothetical perceptual retouch mechanism.

Subjective contrast   Visual masking   Contrast enhancement   Nonspecific perceptual retouch

INTRODUCTION

It is not surprising that in most of the works on visual masking there are no references to the studies of two-transient, short-term interaction in which the "positive" effects of *enhancement* of the perceptual qualities (brightness, contrast) of one of the stimuli are obtained due to the exposure of the other stimulus (e.g. Blanc-Garin, 1972; Donchin and Lindsley, 1965; Geisler, 1978; Shchadrin and Bongard, 1971; Standing and Dodwell, 1972). The facts from this rare group of studies pose serious problems for most of the existing theories of masking, which are usually based on the consideration of "negative" mechanisms such as *inhibition*, contrast *reduction*, *erasure*, processing *interruption*, etc. (for review see Uttal, 1981; Breitmeyer, 1984).

The enhancement effects can be retroactive (Donchin and Lindsley, 1965; Standing and Dodwell, 1972), proactive (Shchadrin and Bongard, 1971; Blanc-Garin, 1972), and simultaneous (Georgeson and Georgeson, 1987). These effects have been obtained both, monoptically/binocularly as well as dichoptically (Shchadrin and Bongard, 1971; Blanc-Garin, 1972). Mostly researchers have used pulses of light and/or laterally-interacting, nonoverlapping stimuli with certain simple form-quality (e.g. in metacontrast). Up to the present knowledge of the author there has been no research on the effect of proactive enhancement, exerted by the first stimulus (S_1) on the apparent contrast of the second stimulus (S_2), given that both are *supraliminal*, *spatially overlapping*, and *spatially structured*, and that the values of the spatiotemporal variables guarantee the similarity of the contrast-enhancement paradigm to the paradigms of pattern masking (mutual masking).

The main purpose of the present research note is to present the results of the experiment in which we tested the possibility that in a pair of two successively exposed, spatially overlapping figures the S_1, besides masking, induces temporary enhancement of S_2 contrast at certain SOAs. The further aim was to test the possible effects of such variables as S_1 energy level, information-processing load on the subject, and the figurative similarity of S_1 and S_2, on the hypothetical functions of S_2 apparent contrast enhancement as dependent on SOA between S_1 and S_2. These variables, usually central to visual masking, could help to provide us with some knowledge about critical factors which would mediate this hypothetical enhancement effect and thus can help us in establishing optimal directions for more systematic future research.

METHOD

Apparatus

A three-channel tachistoscope with semitransparent mirror system, manufactured in T.S.U. Experimental Construction Department, was used in the experiment. It enables the exposure of slides as transparent stimuli. The impulses are generated by the photostimulator FS-02 (manufactured in the Lvov Plant of Radioelectronic Medical Equipment) and they can be commuted between relevant channels of the T-scope. This unit—FS-02—enables production of photic pulses within the frequency range from 0.5 to 50 Hz. Three gas-discharge lamps (type IFK-120) are driven by it; the flashes of lamps are spectrally close to the sunlight. The flash duration equals 2.5 msec; the radiant energy equals 36 J. The relevant values of luminance can be obtained by inserting neutral density filters between the IFK-120 and the clouded glass screen and/or the stimulus slide in each channel of the T-scope.

Stimuli

In the high-figural-similarity set there were six inducing stimuli (IS)—dark capital letters, consonants B, P, M, N, R and F, prepared as high-contrast slides (contrast values of the letters on light background were above 95%). The homogeneous luminous background was provided by the small clouded glass screen behind the stimulus slide. There was also another IS-set of six letters which formed the low-figural-similarity set: X, Z, V, Y, S and T. A letter H served as the test-stimulus (TS), being figuratively more similar to the letters from the high-similarity set and less similar to the letters from the low-similarity set. Besides subjective visual impression of the relatively high vs low spatial overlap of the two sets of ISs with TS, we checked the respective values of figural similarity from the empirical interletter confusion matrix by van der Heijden *et al.* (1984) and calculated the mean "confusion probabilities", P_c, for IS–TS and TS–IS confusion (see respective entries for letter H in the matrix by van der Heijden *et al.*, 1984). With the high-similarity set we found $P_c = 0.053$, while with the low-similarity set $P_c = 0.007$.

The luminous background for the IS and TS was provided by the pulse lamps in channels 1 and 2 of the T-scope, and the dim luminous background for the fixation field was provided by the solid-state light emitting diodes ("Luminophor") with maximum response at 510–520 nm.

The stimulus letters were exposed in the center of a rectangular area (2.25 × 3.4 deg). They subtended 1 deg of the visual angle along the vertical dimension. The fixation dot was located at the center of the imaginary lower perimeter of a stimulus. It was prepared as a transilluminated 3 min hole within the rectangular area of the third channel of the T-scope.

The luminance of the background of the IS letter was varied between the 3 conventionally termed levels—"bright"—10^3 cd/m^2, "medium"—10^2 cd/m^2, and "dim"—10^1 cd/m^2. The luminance of the background of the TS was invariant at 10^1 cd/m^2 throughout the experiment. The luminance of the fixation field equalled about 3 cd/m^2. The luminance was calculated for the eye-distance at 54 cm from the frontal plane of the stimulus image.

Subjects

Four Ss between the ages of 22 and 31 participated in the experiment. All had normal vision and all were experienced in psychophysical tachistoscopic procedures. They were, however, uninformed about the theoretical rationale of the present study.

Procedure

The method of direct magnitude estimation for the measurement of apparent (subjective) contrast was employed. In the training sessions of 50 exposures Ss were familiarized with the procedure and they were allowed to stabilize their subjective estimation criteria: the experimenter first exposed a single TS to a S on the unusual high-contrast level—with the luminance of the background equal to 1.5×10^3 cd/m^2—and assigned a standard value of "10" to its contrast. Then different stimuli were shown to a S in random order at different background intensities (with different contrasts) and both with preceding IS and in isolation and she (he) was asked what would she (he) call the contrast of a TS at a given trial in comparison with the standard? It was stressed that just the contrast of the letter H (the TS) be rated regardless of the possible presentation of other stimuli. It was emphasised, that just the quality of stimulus *contrast*, the degree with which the dark-contoured stimulus subjectively "stands out" on a brighter background, should be estimated. It was also emphasised that Ss try to give the appropriate number to each exposed TS regardless of what he/she may have called the previous stimuli. If no TS image was perceived at all, then the rating value was equalled to zero. The 50 training exposures turned out to be sufficient for stabilization of the Ss' criteria of estimation. (The variability of a training-trial stimulus estimations given their actual energetic invariance did not exceed 1–2 points on a 10-point scale. In the following main experiment the standard error of the grand mean of estimations had an average value equal to 0.15 and the SD = 1.27.)

The main session was organized as the counterbalanced blocks of trials with one of the two types of task in each block: (1) simple TS contrast estimation; (2) contrast estimation for the TS combined with the task of recognition of the IS preceding the TS at the same spatial locus, given its exposure. (For this additional task the forced response scheme was used).* Within each block of trials there were randomly intermixed trials of paired IS–TS exposure and of single-TS exposure (control conditions). The other independent variables were—luminance/contrast of the IS at 3 levels (see Stimuli section); high vs low figural similarity of IS and TS at 2 levels (see Stimuli section); SOA at 6 levels—20, 40, 70, 110, 160 and 290 msec. Thus the 5-factorial hemibalanced design was employed.

Each trial consisted of an aural warning, followed by fixation at the fixation dot at the center of the adapting field, this in turn followed after 1 sec by the exposure of either the TS or the IS–TS sequence with variable SOA, and then a S's response. A S had to give a value of 0, 1, 2, 3, 4, 5, 6, 7, 8 or 9 to the TS′ apparent contrast.

Each IS and TS was exposed for 2.5 msec. The Ss' responses were recorded by the experimenter's assistant. The interval between the trials equalled about 10–13 sec. After each series of 24 trials there was a leisure-break for a minute or two without change in the eye's adaptation level. A daily session consisted of about 12 series with each S. The interval between sessions was about 24 hours. The room illumination was kept constant at 10 lx.

For each unique condition there were 24 trials with equal number of unique IS–TS pairings. Thus each S received $2 \times 2 \times 3 \times 2 \times 6 \times 24 = 3456$ trials in total.

RESULTS

The results were analysed as the mean estimations above the baseline for different experimental conditions and a couple of 3- and 2-way ANOVAs with alternate specification of the random factors were run. For each experimental condition a respective mean of the control condition—a zero baselevel—was calculated and the results are expressed in terms of scaled mean estimations. While all Ss gave very similar results then our graphs depict pooled data across 4 Ss.

Figure 1 shows mean TS contrast estimations as a function of SOA, with IS intensity level as the parameter. It is apparent that with short SOAs (20 and 40 msec) there is a forward masking effect (contrast reduction due to luminance summation?) that is the higher, the higher the level of IS intensity. With medium and

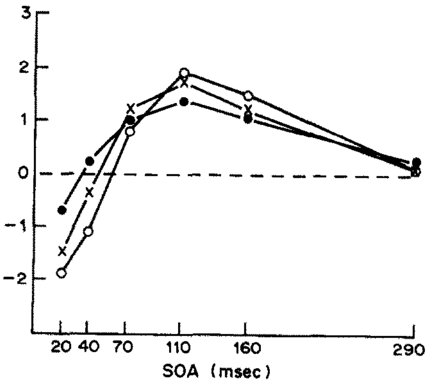

Fig. 1. Mean contrast estimations for the second, test stimulus (TS) as a function of SOA between IS and TS and intensity level of the first, inducing stimulus (IS). The means are depicted relative to the mean of the single-stimulus control (this baseline equalled to zero). The open symbols—bright IS; crosses—medium-level IS; filled symbols—dim IS.

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*We also ran a pilot session where the Ss had to give paired estimations to both IS and TS, viz. if the IS appeared dim and TS appeared high-contrasted, a S would give an estimation like "2–7". The results of this session with regard to the TS estimates did not differ significantly from the results of TS estimation in the main study.

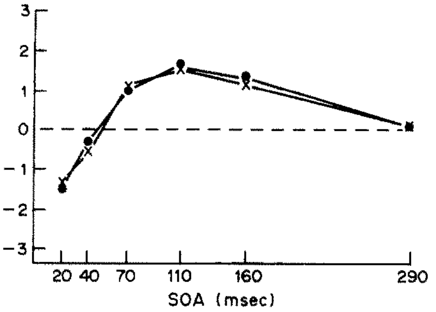

Fig. 2. Mean contrast estimations for the TS as a function of SOA between IS and TS and figural similarity (confusability) of IS and TS. Filled symbols—high similarity; crosses—low similarity.

longer SOAs, however, there is an effect of TS contrast enhancement (at 70–160 msec SOA), which varies directly with IS intensity level (at 110–160 msec SOA). These effects subside at SOA = 290 msec. The main effect of IS intensity was highly significant indeed (d.f. 1, 2; $F = 617.457$; $P < 0.002$) as was the interaction between SOA and intensity (d.f. 10, 10; $F = 6.383$; $P < 0.004$). The main effect of SOA was highly significant (d.f. 5, 5; $F = 140.944$; $P < 0.0001$).

Figure 2 depicts mean TS contrast ratings as a function of SOA, with IS–TS figural similarity as the parameter. The general picture of very-short-term forward masking giving way to contrast enhancement at longer SOAs is preserved, but the lack of considerable effect of IS–TS figural similarity (confusability) is also evident (d.f. 1, 2; $F = 0.674$; $P = 0.498$), as well as the lack of interaction between overlap/similarity and SOA (d.f. 5, 10; $F = 0.337$; $P = 0.879$). This refers to the figuratively nonspecific nature of the contrast enhancement phenomenon, at least within certain minimum spatial locus (here = 1 deg of the visual angle).

Figure 3 illustrates how the contrast estimations of TS "interact" with the average recognition function for the IS (a backward masking function). We see that in general the lower the recognition efficiency for the first stimulus, the higher the subjective contrast function for the second stimulus, and vice versa.

A result worth mentioning was the main effect of Ss' task (d.f. 1, 1; $F = 268.086$; $P < 0.039$). In general, the Ss gave higher contrast estimations for the temporally trailing TS if this was their sole task; with the double task, requiring higher information-processing load due to the recognition of the preceding IS, these estimations were lower. But this was mainly based on the results at intermediate SOAs (70, 110, 160 msec); the respective interaction between task and SOA was also significant (d.f. 5, 10; $F = 3.953$; $P < 0.031$). If the Ss had to pay attention to the first stimulus, the apparent contrast of the second stimulus (at the SOAs with strong backward masking!) suffered. Consequently we may hypothesize that an attention-focusing process of limited capacity may play some role in determining subjective clarity of the stimuli. But the fact that even with the attention payed to the first stimulus identification the curvilinear enhancement function for the second stimulus contrast remains present, points to the highly spontaneous, nonvoluntary heritage of the phenomenon.

There was also a slight tendency (d.f. 1, 2; $F = 6.167$; $P < 0.131$) for the interaction between task and the level of stimulus similarity. In fact, if the Ss had to recognize the IS, then attention was more involved in analysing visual features of the IS and the stimuli with higher level of mutual similarity between IS and TS lead to a bit higher contrast estimations than the stimuli with lower level of figural similarity. But in the task of rating the TS without IS recognition just the low-similarity conditions have lead to a bit higher contrast estimations for the TS. This tendency clearly invalidates the form-specific contrast enhancement explanation based on the summation effects. It is clear, that in recognition tasks within the masking paradigm these summation effects could play some role (cf. Hellige *et al.*, 1979; Schultz and

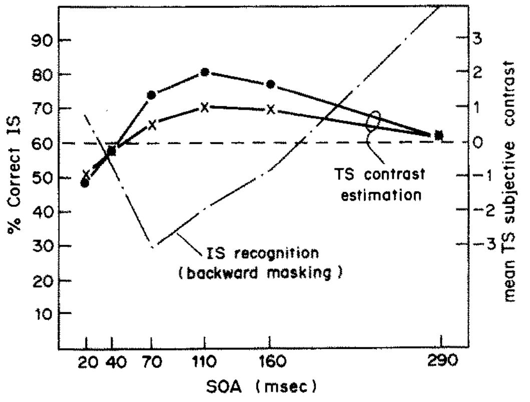

Fig. 3. Mean contrast estimations for the TS as a function of SOA and subjects' task (sole estimation vs estimation plus IS recognition) and average per cent correct for IS recognition as a function of SOA. Filled symbols—TS estimation task; crosses—TS estimation and IS recognition tasks combined.

Eriksen, 1977; Navon and Purcell, 1981), especially at short SOAs, but they are additive or orthogonal to the nonspecific effects of temporally displaced contrast enhancement.

DISCUSSION

The experimental results reported here help to point out some conditions which are sufficient to obtain the effect of proactive apparent contrast enhancement for the second stimulus in a pair of successively presented, spatially overlapping, and figuratively differentiated (spatially articulated) stimuli: (1) The IS and TS are spatially localized, relatively small (about 1 deg of the visual angle), transient (2.5 msec) stimulus figures of approximately equal size and of considerable contrast.* Within this spatial focus the *figural* characteristics of the stimuli are relatively unimportant—contrast enhancement effect is nonspecific within this spatial constraint [an analoguous nonspecificity in terms of figural characteristics within the masking paradigm has been found by Gummerman *et al.* (1974) for the backward *masking* effect]. The facts that large stimuli and stimuli with controlled spatial frequency content may behave differently can be found in the studies by Koenderink and van Doorn (1979) and Georgeson and Georgeson (1987). (2) Both IS and TS are suprathreshold if exposed singly (unpaired). (3) For the robust contrast enhancement effect the intensity and/or contrast of the IS should be higher than that of TS. (4) The optimal temporal intervals between the IS and TS for obtaining TS contrast enhancement include 40 msec < SOA < 250 msec. (At shorter SOAs luminance summation/contrast reduction takes place.)

With increase in IS energy level the suppression (masking) effect of IS on TS extends to longer SOAs, but the enhancement effect, although arriving now at longer SOAs, is considerably more pronounced (cf. Fig. 1). This result is at odds with the data by Georgeson and Georgeson (1987), who obtained facilitation only with simultaneous exposure of the stimuli; at the whole range of SOAs only masking was found. This discrepancy may stem from the considerable size differences between the stimuli (1 deg in our study and 6 × 5 deg in their study), from the fact that their paradigm belongs to the threshold domain (contrary to our suprathreshold domain), and from the fact that the stimuli, used by the Georgesons—the sine-wave gratings—lacked abrupt spatial gradients.†

The importance of abrupt *temporal* onset for obtaining enhancement effects can be deduced from the data of the above-cited Georgesons' paper as well as from the work by Kitterle and Corwin (1983), although in the latter case the authors employed single transients in order to obtain the Broca–Sulzer effect-like phenomenon with the spatially structured stimuli. In another study (Kitterle and Beard, 1983) it was found that if subjects were adapted to the flickering low-frequency grating, then the contrast enhancement effect disappeared. This again refers to the importance of transients in obtaining some temporal optimum for spatial contrast enhancement. The study by Petry *et al.* (1979) may help to relate the effects of flickering-stimulus adaptation to the masking paradigms. They showed that metacontrast masking was considerably reduced when prior to each trial Ss had been selectively adapted to flickering MS (the optimal frequency being 7.7 Hz, which is close to the optimal frequency needed to obtain EEG synchronization). But to relate all this research to the phenomenon described here, seems premature.

What about the theories of masking in the light of the S_2 contrast enhancement effect found at nonzero delays between S_1 and S_2? Retinal interactions can hardly be considered as the basis for it, because the proactive enhancement phenomena of similar time-course and with similar-sized stimuli have been found with *dichoptic* exposure of IS and TS (Shchadrin and Bongard, 1971; Blanc-Garin, 1972). One referee has suggested that a phenomenon, sometimes found in backward masking—the TS (but in our case the IS) brightness reversal—may help to explain our results (for the review of the reversal effect cf. Breitmeyer, 1984): In the case of the backward-masked IS, contrast being reversed, the trailing TS may seem to be relatively more contrasted as compared to the single-TS control

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*Here we used stimuli with negative contrast. Our unpublished data indicates that similar effects can be obtained with positive-contrast stimuli on dark background.

†It should be noticed, however, that if one is to carefully observe the Figs 4, 6, and 9 of the Georgeson and Georgeson (1987), then at SOA = −200 msec and with 1 c/deg, above-threshold, mask, one may notice a little facilitation (cf. Fig. 4); at 0 < SOA < 200 with 4 c/deg TS, facilitation may be present at least for one of the Ss (Fig. 6); the same applies to SOA > 150 msec, for 1 c/deg test, with the test contrast reversal condition (Fig. 9).

condition. One regularity in our data seems contradictory to this proposal, however. If we look at Fig. 3, then we notice that there is a region of SOAs—70–110 msec—where both recognition function of retroactive masking and proactive enhancement function of contrast estimation rise, i.e. the contrast of the IS should increase here in parallel with the increase of TS contrast. This temporary loss of reciprocity of IS and TS efficiency is inconsistent with the contrast-reversal hypothesis.

The theory of masking which is based on luminance-summation/contrast-reduction assumptions is compatible with the data only at short SOAs. It cannot explain the enhancement effect at longer SOAs. The transient-on-sustained *inhibition* theory likewise has difficult times in explaining the curvilinear *facilitation* effect unless it will treat facilitation in relativistic terms (the more the trailing-TS-transients inhibit the IS, sustained response, the higher the *relative* TS contrast).

Recently we have proposed a nonspecific masking theory which is based on the concept of "perceptual retouch" (Bachmann, 1984). Instead of *inhibition* or interruption of the activity of channels which are responsible for the TS coding at the cortical levels it was supposed that the *nonspecific thalamic facilitation* plays crucial role in two-transient masking: It is known for several decades that for conscious-experience generation the convergence of both specific retino-geniculo-cortical afferent impulses and nonspecific thalamo-cortical impulses is necessary. Also it is pretty well-known that the latter are slower in terms of average time of reaching cortical areas which represent specific stimulus information. (This specific information *per se* is insufficient, although necessary for the awareness of its content.) There is an anisochrony in the peak cortical activity of the specific and nonspecific afferents. Thus if two transient stimuli arrive in rapid succession, say, with SOA = 70 msec, an association of the first-stimulus' *non-specific* impulses with the second-stimulus' *specific* impulses occurs. In other words, the specific afferents which are coding the S_2 at the cortical level literally use the nonspecific activation, evoked by the previous S_1 which had the same retinotopic coordinates (c.f. cortically focal character of nonspecific phasic thalamo-cortical input, Smirnov *et al.*, 1978). Whereas at the moment of the first peak of the activity of the nonspecific ("retouching") processes the signal-to-noise ratio of the specific ("retouchable") cortical afferents of the S_2 is higher than that for the S_1, then just the S_2 is better visible; it has a higher subjective contrast value. (See also Smirnov *et al.*, 1978, who describe how the direct stimulation of selected nonspecific thalamic structures can lead to the experience of higher contrast and clarity of visual images.) This conceptualization also predicts that beginning with the intermediate values of SOA, the TS contrast is dependent on IS intensity, because the TS afferents "use" the IS-evoked "retouch" process. It was exactly so in our experiment. Thus the perceptual retouch theory seems compatible with the psychophysical proactive contrast enhancement effect as well as with some other similar forward facilitation effects found in the area of visual attention research (Sokolov, 1963; Eriksen and St James, 1986; Possamai, 1986; Reeves and Sperling, 1986).

One may also notice that the time course of the contrast enhancement is coinciding fairly well with the time course of the evoked response component $N_{100-150}$, which is often considered to be an index of sensory attention and/or an index of nonspecific cortical input, and the amplitude of which has been shown to vary directly with sensitivity to those stimuli that evoke it (Hassler, 1978; Harter and Aine, 1984; Ivanitsky, 1976). Of course, the problem of linear dependencies between transient psychophysical input and the ERP is far from being settled (cf. Spekreijse and van der Tweel, 1972; Uttal, 1981). Similarly, the experimental facts about the contrast enhancement are *compatible* with the retouch theory while *direct dependencies* between apparent contrast and the time-course of nonspecific cortically localized activation remain to be investigated in the more sophisticated future research.

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