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ORIGINAL ARTICLE

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Visual attention and the mechanism of metacontrast

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Abstract The U-shaped metacontrast function may result from the superimposition of two monotonic components which reflect the effects of mechanisms similar to the peripheral and central processes suggested for backward pattern masking by Turvey (Psychol Rev 80:1–52, 1973). In an experiment using the disc-ring paradigm, it was demonstrated that the decreasing and increasing branches of the metacontrast function are differently affected by the exposure duration of the mask and a task-irrelevant stimulus (distractor) appearing in the contralateral visual hemifield. The phenomenal representation of masking is different for the two parts of the curve. It is suggested that masking in the second part of the masking function, but not in the first, is related to the control of visual attention.

Introduction (see endnote 1)

The experiments reported are concerned with a visual phenomenon that has been discovered almost 70 years ago by the Vienna physiologist Robert Stigler and which he termed 'metaphotic contrast' ('metaphotischer Kontrast'; Stigler, 1910). The now common abbreviation 'metacontrast' is derived from this term.

Metacontrast occurs if a briefly presented figure, for example a disc or a rectangle, is followed at a short interval by a second stimulus that is laterally adjacent to it. The visibility of the first stimulus (the *test stimulus*) is then impaired by the second stimulus (the *mask*). This impairment can be a reduction of the perceived brightness (e.g., Alpern, 1953; Blanc-Garin, 1966; Fry, 1934; Growney, Weisstein, & Cox, 1977; Piéron, 1935), an increased threshold for the test stimulus (e.g., Cox & Dember, 1970; Kolers, 1962; Lefton & Orr, 1975), its reduced discriminability (e.g., Bernstein, Proctor, Proctor, & Schurman, 1973; Breitmeyer, Love, & Wepman, 1974; Weisstein & Haber, 1965) or identifiability (e.g., Dember, Bryant, & Chambers, 1975; McKeever & Suberi, 1974; Mewhort, Hearty, & Powell, 1978; Schurman, 1972) or simply that it has phenomenally disappeared (e.g., Burchard & Lawson, 1973; Kolers & Rosner, 1960; Mayzner, Tresselt, & Helfer, 1967; Toch, 1956; Werner, 1935).

The data have typically been presented by plotting the measure of test stimulus visibility against the interstimulus interval (ISI) or stimulus onset asynchrony (SOA) between the test stimulus and the mask. These curves are U-shaped, which is typical for metacontrast. The impairment caused by the mask is small at very short intervals, reaches a maximum in the range of approximately 40–80 ms and is again reduced if the interval is further increased. (In the following text, we will call the two slopes of this function the decreasing and the increasing branches of the masking function. The decreasing branch comprises the short SOAs where visibility decreases, and hence masking strength grows. In the increasing branch, at longer SOAs, performance recovers, and hence masking strength declines.) Two types of models which differ in their underlying idea may explain this U-shaped function.

The first possibility is that metacontrast is based on a mechanism which works best within a certain interval between the test stimulus and the mask. The decreasing and the increasing branches of the metacontrast function would thus reflect the decreasing effectiveness of this mechanism if the intervals either fall below this optimal value or exceed it. For example, Kahneman (1967) has proposed that this mechanism could be the same that is also responsible for apparent motion. This explanation has, however, met with several empirical difficulties (Stoper & Banffy, 1977; Weisstein & Growney, 1969). At present, an approach that makes use of recent findings from neurophysiology appears more promising (Breitmeyer & Ganz, 1976; see also Matin, 1975; Weisstein,

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Ozog, & Szog, 1975). This explanation attributes metacontrast to the fact that the activity elicited by the test stimulus in the sustained neuronal channels is inhibited by the transient activity caused by the mask. According to Breitmeyer and Ganz (1976), the different processing speed of these two types of channels explains why maximal masking is observed only with a certain interval. They suppose that transient activity reaches the cortex about 50–100 ms earlier than sustained activity. In order for the two to become synchronized, the mask has to be delayed by a corresponding interval.

Like Kahneman (1967), Breitmeyer and Ganz (1976) assume that the U-shaped function results from a decrease in the effect of one factor (apparent motion or inhibition) as the interval between the test stimulus and the mask diverges from an optimal value—in one or the other direction. A second, less often discussed possibility (see Merikle, 1977; Turvey, 1973, p. 40f.) to explain the U-shaped metacontrast function is the superpositioning of two monotonic components that are affected in opposite directions by the interval between the test stimulus and the mask. The increase of metacontrast in the decreasing branch of the masking function may be due to a mechanism wherein masking effectiveness *increases* monotonously with the interval, whereas the decrease of masking beyond the maximum relies on a different mechanism which becomes more *ineffective* as the interval between the test stimulus and the mask becomes larger.

There are three empirical arguments in favour of this hypothesis that justify its experimental investigation:

1. The data suggest that certain experimental variables differentially influence the decreasing branch of the function:

   - Increasing the *exposure duration* of the mask or shortening the exposure duration of the test stimulus considerably enhances masking in the decreasing branch, but has only a marginal effect in the increasing branch (Alpern, 1953; Blanc-Garin, 1966; Merikle, 1977).
   - The difference between *monoptic* and *dichoptic presentation* is largely restricted to the decreasing branch (Growney & Weisstein, 1972; Schiller & Smith, 1968; Weisstein & Growney, 1969).
   - A third variable mainly effective in the decreasing branch is the *spatial distance* between the test stimulus and the mask (Growney, 1976; Lefton, 1973; Merikle, 1977). However, these data are less clear than in the two preceding cases (see Alpern, 1953; Growney, Weisstein, & Cox, 1977).

   Other variables seem to predominantly affect the branch of the metacontrast function in which performance is increasing:

   - The *number of elements* from which the test stimulus has to be reported is almost irrelevant with short intervals, but exerts a massive influence on the strength of the metacontrast in the second part of the masking function (Weisstein, 1966).
   - Only this part of the function seems to be sensitive to whether the mask belongs to the same *cognitive category* as the test stimulus (Merikle, 1977).

This pattern suggests that the second part of the metacontrast function reflects 'higher' information processing, whereas the mechanism which is responsible for the first part is located more peripherally. This assumption would also resolve an obvious difficulty of all single-mechanism models of metacontrast. On the one hand, the masking function can be well predicted from physical stimulus parameters (e.g., Bridgeman, 1971; Weisstein, 1968); this suggests localizing metacontrast at early stimulus processing stages. On the other hand, metacontrast is also sensitive to factors such as figural similarity between the test stimulus and the mask (Fehrer, 1965; Toch, 1956; Uttal, 1970) and even to whether the test stimulus can be encoded as a word (Mayzner & Tresselt, 1970). This suggests a later 'locus' of masking. If the view taken here is correct, these would be complementary, not alternative, localizations of the mechanisms of metacontrast masking.

2. This hypothesis is further supported by a comparison between the masking functions of individual subjects. Several experiments have demonstrated that individual differences can be quite differently pronounced in the two parts of the metacontrast function. Burchard and Lawson (1973), for instance, found masking functions whose increasing branches were displaced up to 70 ms between individual subjects, whereas individual performance was essentially the same in the decreasing branch. Conversely, Eriksen, Becker, and Hoffman (1970) reported different courses of the masking function in the first part, but good agreement between subjects in the second.

These findings can be understood if we suppose that the two parts of the metacontrast function are based on two different mechanisms and that the effects of these mechanisms are phenomenally represented in different ways. Depending on the experimental conditions and the subject sample, subjects might then differ in their ability to cope with one or the other perceptual impairment of the test stimulus. This interpretation is supported by the observation of Schurman (1972) that trained observers differed from untrained observers mainly in their performance at short masking intervals, presumably because they were better at perceptually isolating the test stimulus when it was integrated with the mask into a single percept. Together with similar results from Ira Bernstein and coworkers (Bernstein, Proctor, Belcher, & Schurman, 1974; Bernstein, Proctor, Proctor, & Schurman, 1973), this suggests that the assumption that the two parts of the masking function and the two hypothetical mechanisms of metacontrast could at the phenomenal level be paralleled, respectively, by temporal integration between the test stimulus and the mask versus the perception of a succession. In other words, masking effectiveness in the range of the decreasing branch depends on how well the test stimulus can be perceived if it is temporally and figurally integrated with the test stimulus, whereas the gradual decrease of masking in the increasing branch reflects the fact that the test stimulus becomes increasingly visible in the form of a separate visual object as the SOA increases.

3. The third argument for a two-component theory of metacontrast is based on a comparison with a related experimental paradigm. In the so-called pattern masking, the test stimulus—usually a letter or an array of letters—is followed by an overlapping visual pattern of randomly distributed figural elements. As shown mainly by the work of Spencer (Spencer, 1969; Spencer & Shuntich, 1970), Scheerer (Scheerer, 1973; Scheerer & Bongartz, 1973), and Turvey (1973), the data require at least two mechanisms of masking. The first, located at an early stage of processing, is affected by physical variables such as exposure duration and intensity and is confined to the temporal range in which the test stimulus and the mask form a common percept. The second mechanism belongs to a more central stage of processing and is hence sensitive to the processing load and the time available for processing prior to the arrival of the mask. Its effectiveness extends into the temporal range in which test stimulus and mask are no longer integrated into a common percept.

It is apparent that this two-factor concept of pattern masking strongly resembles the ideas about the functional basis of metacontrast sketched so far. This correspondence is quite interesting since the respective data material stems from different experiments that are usually supposed to study different phenomena. Metacontrast and pattern masking may be functionally more similar than is suggested by their appearance.

The considerations presented so far rely mainly on comparisons among data from different experiments. Further, they have often been secondary findings, not central to the purpose of the experiment, and they have not always been confirmed.

The purpose of our experiment was therefore to directly demonstrate the hypothesized differences. We tried to answer two questions: (1) Are there experimental variables that selectively influence the decreasing branch of the masking function and others that affect exclusively, or at least mainly, the increasing branch? (2) Is the effect of masking represented in phenomenally different ways in the decreasing and increasing branches of the masking function?

Methods

The stimuli were similar to the disc-ring display of Werner (1935). A black disk was presented for 5 ms to the right of fixation (see endnote 2). After an interstimulus interval of 0–100 ms, a surrounding ring followed as the mask. The two factors that we expected to influence the two parts of the masking function in different ways were:

1. The exposure duration of the mask, which was 5, 7.5, or 10 ms
2. The presentation of an additional stimulus (distractor) which was identical to the test stimulus in shape, size, and exposure duration. In the condition 'with distractor', the disc appeared simultaneously with the test stimulus at the same distance from fixation, but in the opposite (left) visual hemifield.

These two variables were partly chosen on the basis of results from pilot experiments, but they were also in agreement with the literature. We expected the exposure duration of the mask to primarily affect the decreasing branch, hence the more peripheral mechanism; however, the distractor was expected to affect central processing and thus the second part of the function.

The second intention of the experiment was to investigate the phenomenal representation of the mask. Observers were asked to give judgments according to three criteria:

1. *Detection*: The observer said 'yes' if he was certain to have perceived the test stimulus, otherwise he said 'no'. This instruction leaves open how the test stimulus is phenomenally represented if the observer detects it.
2. *Scaling*: Perceived darkness of the test stimulus was judged on a 5-point scale in which 1 was assigned to 'white' and 5 to 'black'.
3. *Temporal resolution*: The observer reported whether he had perceived a succession. These latter two kinds of judgments provide information about how the test stimulus was phenomenally represented.

The three kinds of judgments were mapped onto two response conditions. In the first condition, the observer only judged detection. In the second condition, he judged darkness and temporal resolution. A report "2–4", for instance, meant that the test stimulus and the mask were perceived in succession ("2"), and that the test stimulus had a darkness of "4". If no succession was perceived, the darkness of the inner region of the ring was to be scaled.

This led to the following design. The interval between the test stimulus and the mask was varied in ten steps (see endnote 3); the exposure duration of the mask had three values. Further, there was the factor 'with/without distractor'. In addition, there were the two response conditions. Each cell of the design was repeated 20 times for each of three trained observers.

The response conditions varied blockwise. Stimuli were presented in a Scientific Prototype tachistoscope, model GB. The black stimuli were presented at a distance of 120 cm on a white display field of 7° × 5° of visual angle and with a luminance of 40 cd/m^2. The diameter of the disc and the inner diameter of the ring were 27, the width of the ring was 13.5 min of visual angle. The test stimulus appeared 0.54 min to the right of fixation, and the otherwise identical distractor at the same distance left of fixation. The ten interstimulus intervals were 0, 10, 20, 30, 40, 60, 70, 80, 90, and 100 ms.

The temporal parameters were controlled by a Massey–Dickinson system. The experimenter adjusted the distractor by moving a pasteboard behind a circular hole in the display. After a signal from the experimenter, the observer manually triggered the sequence and then gave the judgment according to the response condition.

Results and discussion

The response condition 'detection' in which the observer decides whether the test stimulus is visible has been used in a number of classical experiments on metacontrast (e.g., Werner, 1935; Kolers & Rosner, 1960; Mayzner, 1975). Thus, we expected the usual U-shaped metacontrast function.

As Fig. 1 shows, this was indeed the case. (The data of the three observers have been averaged because they did not differ significantly.) Besides the ISI, the factors 'exposure duration' (denoted by different symbols) and 'distractor' also influenced detection judgments. In the decreasing branch, the probability of detection does not seem to be affected by the distractor. However, the distractor massively affects the increasing branch, shifting it by approximately 30 ms to the right. Conversely, exposure duration of the ring has its effect primarily on the decreasing branch. Contrary to our expectations, it is not completely without influence in the second part, though its effect is much smaller than in the decreasing branch.

Let us now look at the data from the second response condition in which the observer had to judge temporal resolution and perceived darkness. Figure 2 depicts the scaling data separately for whether the darkness judgment was accompanied by perceiving a succession of test stimulus and mask (curves in the upper right) or whether the observer perceived a single visual object (curves to the left).

In the absence of temporal resolution, the time course of scaled darkness is very similar to that of detection in the decreasing branch. Again, there is an influence of the exposure duration of the ring, whereas the distractor has no impact.

The fact that detection and scaling data behaved similarly in the decreasing branch suggests that these two variables measure the same thing—more exactly, that the effect of the mask consists of a reduction of the perceived darkness of the test stimulus in the inner part of the ring, with detection judgments being based on this perceived darkness. It turns out that there is a simple relationship between these two variables.

Figure 3 depicts the z-transformed probability of detection as a function of scaled darkness for intervals up to 30 ms. The values lie on a single regression line. Thus, the relationship between 'scaled darkness' and 'detection probability' is a classical threshold function for the decreasing branch of the metacontrast curve.

Let us return to the darkness curves (Fig. 2). With intervals of more than 40 ms, the resemblance of judged darkness to the detection curves vanishes. For the latter, a monotonic increase begins. In contrast, scaled darkness remains at the low level reached at approximately 40 ms if the observer does not perceive succession. That is, the inner region of the ring appears nearly white. If, however, the test stimulus is perceived as a separate object, it appears even darker than at the shortest intervals. In other words, in contrast to the decreasing branch, perceived darkness in the second part increases abruptly, and this coincides with the perception of a succession of the test stimulus and the mask.

Let us now look at this transition to the perception of succession, that is the threshold function for temporal resolution. Figure 4 depicts the probability of temporal resolution as a function of the interval between the test stimulus and the mask. The values can roughly be assigned to two threshold functions, one for conditions with distractor and one for conditions without distractor. The threshold for temporal resolution is increased by about 30 ms if a distractor is presented. Thus, the distractor appears to have the same influence on temporal resolution as on the increasing branch of the detection curve; in both cases, the effect of exposure duration is small.

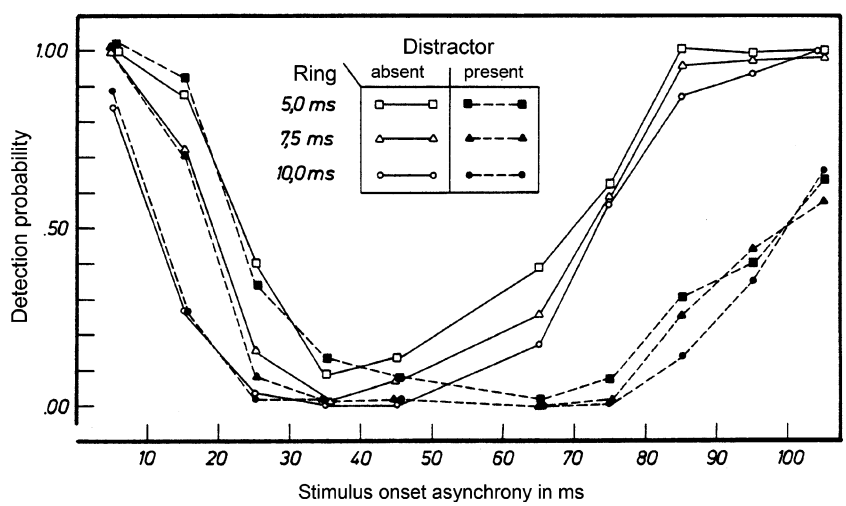

Fig. 1 Probability of a 'yes' response in response condition 'detection'. The data of the three observers are combined. The abscissa depicts the SOA, which, due to the constant exposure duration of the test stimulus in all conditions, was 5 ms longer than the ISI

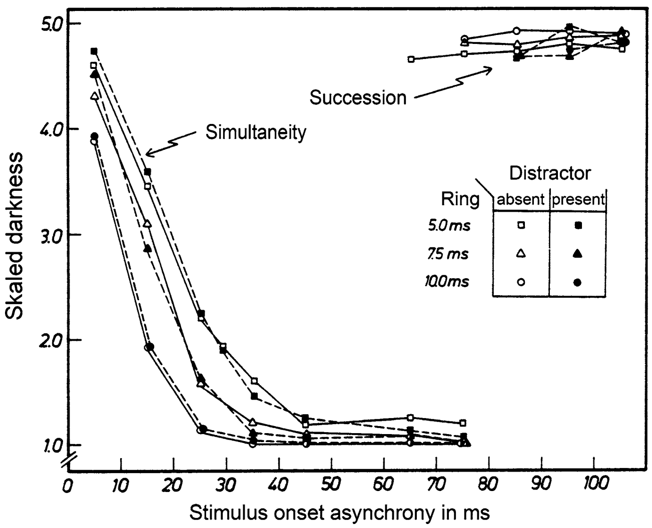

Fig. 2 Results of scaling the perceived darkness of the test stimulus. The observer used a 5-point category scale, with 5 meaning 'black', and 1 'white'. In the case of perceived succession, the judgment was to be based on the first one of the two stimuli (the disk), in the case of integration of test and mask on the inner part of the ring. The two sets of curves show the median scaling values of the three observers separately for these two cases (simultaneity and succession)

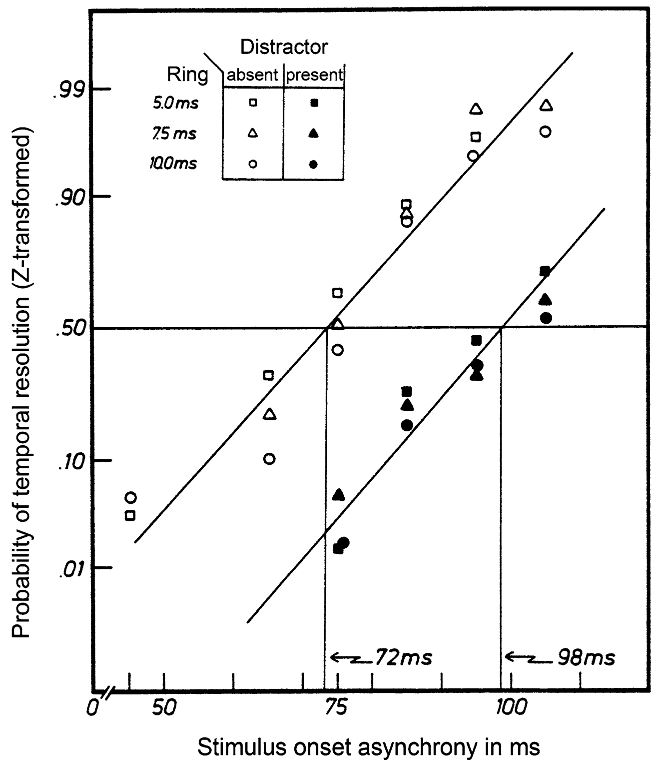

Fig. 4 Probability of temporal resolution (judgment 'succession') depending on stimulus conditions. The resolution threshold is increased by the distractor by about 30 ms. Missing values in the figure are due to $P = 0.00$, respectively, $P = 1.00$

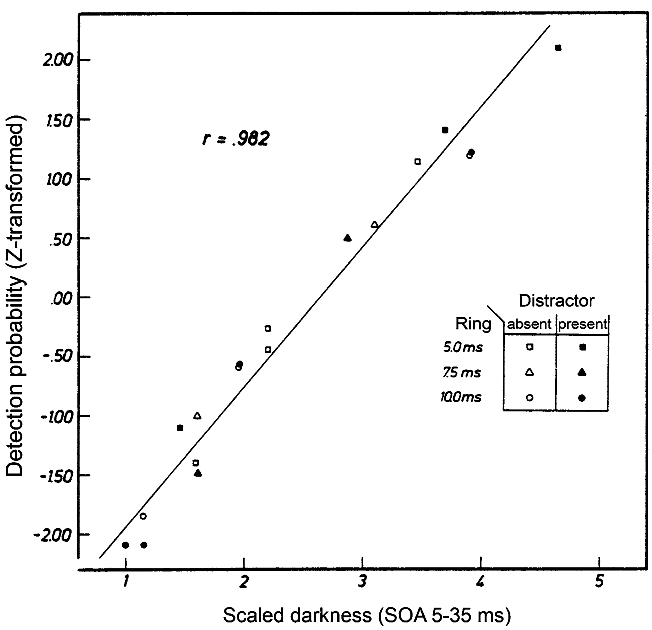

Fig. 3 Relationship between scaled darkness and probability of detection for SOAs up to 35 ms. The data points each represent a combination of interval, exposure duration, and distractor condition. The data of the three observers were averaged

This suggests that temporal resolution has the same importance for detection in the range of increase as perceived darkness has for the decreasing branch of the curve. This assumption can easily be tested by the correlation of detection and temporal resolution in the increasing branch.

In Fig. 5, this correlation is depicted for the 30 combinations of 5 intervals, 3 exposure durations, and 2 distractor conditions. As can be seen, the probability of detection is practically identical to the probability of temporal resolution for each of the parameter combinations.

Conclusions

The experiment has rather clearly confirmed the assumption that the U-shaped metacontrast function is due to the superimposition of two monotonous components. The initial increase of masking, as the interval increases, consists of a progressive brightening of the disc as long as it is perceived as being temporarily integrated with the ring. This kind of masking is sensitive to the exposure duration of the ring, but is not influenced by an additional distractor. The increase of the function, and hence the decrease of masking beyond the maximum, is paralleled by an increased probability of perceiving a succession of test stimulus and mask. This is accompanied by an abrupt change in the perceived darkness of the test stimulus. The threshold for temporal resolution is increased by about 30 ms by a distractor which is presented simultaneously with the test stimulus in the opposite visual hemifield. In contrast, it is only slightly affected by the exposure duration of the mask.

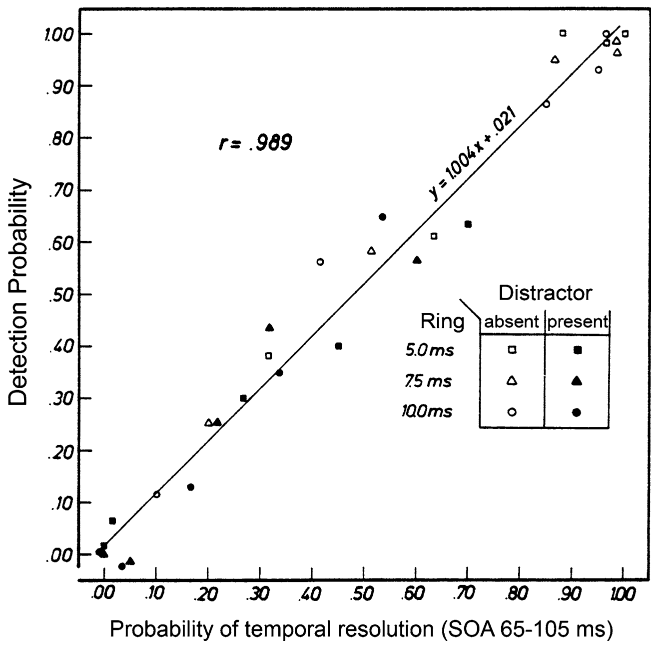

Fig. 5 Correlation between probability of temporal resolution and probability of detection in response condition 2

What does this decomposition of the masking function mean for the functional basis of metacontrast? At a general level, it implies that we can see the same coexistence of 'peripheral' and 'central' processes as in pattern masking (Scheerer, 1973; Turvey, 1973). Thus, it would be at least uneconomical to assume a separate *mechanism* for metacontrast. This is not to deny that the special conditions of the present experiment produced effects that are not seen in other forms of backward masking. These may include the effect of a distractor that we have found.

In conclusion, some considerations about the possible functional basis of the distractor effect are presented. Quite obviously, it is not retinal in origin. This is evidenced, for example, by the fact that it only shows up with longer intervals and leaves perceived darkness unaffected. In order to more precisely locate this central stage of processing we have tried to find out which property of the distractor is responsible for its effect. Results from unpublished experiments indicate that the effect vanished with a stationary distractor and that it could be found not only with a suddenly appearing, but also with a suddenly disappearing distractor. Thus, it is elicited by a response of the visual system to the *appearance or disappearance* of the distractor and not to its *presence*. Physiologically, this could mean that the transient response to the distractor is of decisive importance.

If one assumes, according to the hypothesis of Breitmeyer and Ganz (1976), that the purpose of the transient channels is to control visual attention, we can derive the following provisional assumption about the effect of the distractor: a stimulus which appears simultaneously with the relevant test stimulus in the visual field elicits a competing signal for the allocation of attention. As a result, shifting attention to the test stimulus is delayed. As long as the test stimulus has not been consciously attended to, it remains susceptible to masking by the ring. Hence, the temporal range of masking increases to the extent that the distractor, in its competition with the test stimulus, draws attention towards itself (see endnote 4).

Endnotes

1. This text was originally published in German as an Internal Report of the University of Bochum, Germany, in 1978, Neumann, O. (1978). *Visuelle Aufmerksamkeit und der Mechanismus des Metakontrasts.* [Visual attention and the mechanism of metacontrast.] Report No. 6/1978, Department of Psychology at the Ruhr-University of Bochum, Cognitive Psychology Unit. Its main topic—sensory versus attentional components in metacontrast—has retained its significance in masking research during the years following its publication. Talis Bachmann has kindly provided the opportunity to make the paper available to a broader scientific community by publishing it in the present special issue of *Psychological Research*. Heike Hartwig-Jakobs and Ingrid Scharlau translated the manuscript. Ingrid Scharlau also shortened it and provided the footnotes. Because of the editorial work, she now appears as a co-author. The editorial references are included in a separate reference list.

2. The instruction to the subjects was to report whether they *saw* the test stimulus, not whether they could infer its presence from any cues, such as an expanding motion of the ring (which often accompanies disc-ring displays as the present). They were to adopt a fairly conservative criterion, that is, report the presence of a disk if and only if they saw "something" in the ring, either preceding it or simultaneously. Thus, detection was not forced choice, but similar to the determination of an absolute threshold with the classical method of constant stimuli.

3. The absence of control conditions without test stimulus does not, of course, permit distinguishing between sensitivity and judgmental bias (see endnote 2). However, this was not the experiment's intention. The aim was to demonstrate that the U-shaped detection function as assessed by similar subjective psychophysical methods (e.g., Kolers & Rosner, 1960; Stoper & Banffy, 1977) could be related to two different phenomenal components, as assessed by darkness scaling and temporal order judgment.

4. Metacontrast masking has been independently related to a combination of sensory and attentional or non-specific mechanisms by several authors (e.g., Bachmann, 1994; Bachmann & Allik, 1976; Bachmann, Luiga, & Põder, 2005; Di Lollo, Enns, & Rensink 2000; Enns, 2004; Michaels & Turvey, 1979; Tata, 2002).

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