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Which Mask is the Most Efficient: A Pattern or a Noise? It Depends on the Task

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The aim of the paper is to test the hypothesis that masking efficiency is related to the mask energy on the spatial frequency (SF) range critical to the task, irrespective on whether the mask is a noise or a pattern. Two experiments were run in which targets were fragmented forms of objects masked at various intervals either by a pattern or by the three noise masks varying in the size of their elements. In Experiment 1, in which participants had to discriminate the target global shape (oval vs. round), masking efficiency was directly related to the mask energy on the low SFs critical to this task, whatever the mask. This conclusion extends to the medium to high SF ranges critical to the naming task used in Experiment 2. These results are not compatible with the qualitative noise/pattern distinction used by Turvey (1973) to operationalize his integration/interruption conception of masking. An interpretation in terms of early interactions between SF channels better account for the results.

INTRODUCTION

In addition to being an object of investigation in itself, masking is often used to control the amount of information available for processing in a wide variety of psychological experiments whose major focus is on other phenomena. Massaro and Cohen (1994), for example, studied the effect of a masked prime on target words that were lexically, phonologically, or orthographically related to the prime, and Purcell and Stewart (1991) studied the effect of familiarity on

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the detection of a masked stimulus. Two types of mask are generally used to hamper processing of meaningful, complex targets such as words or pictures: *Pattern masks* are composed of a random distribution of target fragments and *noise masks* are made up of random dots or squares. However, the use of masks to control stimulus visibility is not without problems. A much debated question concerns the amount and the nature of the stimulus information that remains available for processing and for phenomenal awareness after the mask had occurred (see review by Holender, 1986). Further complications arise from the fact that some phenomena, such as the word (or object or face) superiority effect, seem to be so dependent on the presence of a mask (Prinzmetal & Silvers, 1994) that their ecological validity is somewhat questionable.

With respect to the masking phenomenon itself and, as long as only noise and pattern masks are concerned, two major accounts exist in the literature. One is based on information processing theories (Michaels & Turvey, 1979; Turvey, 1973) and the other on neurophysiological and psychophysical theories (Breitmeyer, 1984; Breitmeyer & Ganz, 1976). Turvey (1973) proposed that a noise mask—a mask he assumed having no structural relationship with the target—would disrupt processing by being peripherally integrated with the target. A pattern mask—a mask he assumed being structurally similar to the target—would, in addition, disrupt the target identification processes. Peripheral masking operates at a sensory level by means of an energy-dependent integration mechanism whereas central masking involves interfering with recognition mechanisms by perturbing icon formation. In a subsequent study using a pattern, string of letters, or words as masks, Michaels and Turvey (1979) further distinguished between three types of central mechanism: (1) integration of the mask within the constructed iconic representation of the target; (2) inhibition of the target iconic representation by the activity of the mask; and (3) attention-dependent replacement during the comparison of the iconic representation with the representations stored in memory. Of course, the third mechanism plays little role, with masks having no semantic content.

Breitmeyer's theory (Breitmeyer, 1984; Breitmeyer & Ganz, 1976), on the other hand, stresses interactions between the so-called sustained and transient visual processing channels. It was concluded that early interactions between sustained and transient spatial frequency (SF) channels account for the distinction that Michaels and Turvey (1979) attributed to common iconic synthesis and inhibition of target iconic representation (Breitmeyer, 1984, pp. 248–261). These early interactions among channels are at maximum when the target and the overlapping mask are structurally similar (i.e. when they share similar edges, orientations, or contours, according to Breitmeyer). Indeed, because of the different spatio-temporal properties of the sustained and transient channels, and because of the hierarchical organization of these channels in the primary visual cortex, more sharing of the same visual pathways could occur, as well as more intrachannel and more interchannel inhibition too. Thus, the differential effectiveness of noise and pattern masks observed in Turvey's experiments appears to result from the variable structural proximity of the mask with the target, not from different masking mechanisms.

The distinction between a noise and a pattern mask is indeed not as simple as it first appears. Increasing the size of noise elements in a mask also increases local contour and orientation information (compare for instance the size of the elements of the mask called a noise by Turvey, 1973, p. 3 to the size of those of Breitmeyer, 1984, p. 101). Therefore, a noise mask made up of such large elements can become very similar or even more similar to the target than a pattern mask, at least in some respects. Thus, a mask composed of random target fragments (i.e. a pattern mask according to Turvey, 1973) is not necessarily more similar to the corresponding target than a mask made up of squares (i.e. a noise mask).

Indeed, although the structural similarity between a mask and a target has already been shown to affect the strength of pattern masking (e.g. Hellige, Walsh, Lawrence, & Prasse, 1979), the assessment of similarity rested on intuitive and rather unspecified principles. Because of these ambiguities, it is crucial to be able to clearly specify the properties of targets and masks by using the same metric.

There are two main metrics for specifying visual stimuli that can be used to compute similarity measures between targets and masks. Stimuli can be described in the spatial-frequency domain (Blakemore & Campbell, 1969; Campbell & Robson, 1968; De Valois & De Valois, 1988; Gervais, Harvey, & Roberts, 1984; Ginsburg, 1986) or, in the image domain, by a figural description in the Euclidian space (Caelli & Moraglia, 1987; Caelli & Yuzyk, 1985; Coffin, 1978). The SF description is highly accurate in predicting the masking of one simple grating by another grating (Harvey & Doan, 1990; Stromayer & Julesz, 1972). When targets are two-dimensional meaningful images, processing is no longer limited to the extraction of spectral components, but implies further stages, of which the next one is the combination of SF and orientation information (Olzack & Thomas, 1992). At this level of complexity, there is a tendency to use the subjectively more appealing image-domain descriptions to estimate the structural similarity among stimuli; for example, those based on the distinctive feature model (Gibson, 1969) or the well-known template-overlap model (Caelli & Moraglia, 1987; Coffin, 1978).

However, there are situations involving complex targets and filtered noise masks in which the worth of using SF descriptions to compute similarity is not questioned. For example, in the face recognition task used by Tieger and Ganz (1979), the description of masks and targets in terms of SF provided a fairly good prediction of the degree of masking. The most effective noise mask was the one whose SF content lays in the mid-frequency range because this SF band conveys the information about the salient features of the face (eyes, mouth, and nose).

With unmasked letters presented at a low, near-threshold level of contrast, identification confusions were best predicted by computing interletter similarities from SF information than by any other metrics (Gervais et al., 1984; Harvey, Roberts, & Gervais, 1983). The closer the two-dimensional fast Fourier transform of two letters (estimated by the Euclidean distance between each letter computed from the two amplitude spectra, weighted by phase difference, and filtered with the contrast sensitivity function) the more the letters were confused. The same authors (Harvey et al., 1983) found that the effectiveness of various filtered noise masks in hampering the recognition of landscape photographs was predicted accurately by a SF model of representation. This model took into account the temporal properties of target and mask processing using cross-correlation. These experiments among others (Harmon & Julesz, 1973; Solomon & Pelli, 1994; Vol, Pavlovskaja, & Bondarko, 1990) indicate that, in identification tasks, the SF content of visual figures provides a valuable metric for predicting both near-threshold confusions with unmasked stimuli and masking effects.

In some situations, an image domain description also seems to provide a good prediction of masking efficiency. For example, with targets and masks composed of SF gratings, Caelli and Moraglia (1987) found that masking was closely related to the spatial overlap of the two stimuli in the spatial (x,y) domain. Although this result does not run counter to an explanation based on the amplitude of spectral components, according to the authors it does raise the question of whether the SF-domain description is predictive only because the stimuli were single points in the frequency space or whether this approach could be used for more complex stimuli as well. The results presented in the previous paragraph actually constitute a positive answer to this question, as long as non-filtered target but filtered masks are concerned. The unanswered question, however, is whether an estimation of structural similarity based on the SF content of the stimuli can be predictive for complex objects masked by *non-filtered* structures.

To answer this question, we tested a variety of classical noise and pattern masks which, although not filtered, nevertheless have different spectral characteristics. The rationale is that masking efficiency should depend on the energy of the mask on the SF band that is critical to the task. If the mask SF content allows valuable prediction of masking effects, only the SF band necessary for the task has to be considered: The more energy the mask has on the critical SF band, the more it should perturb target processing. Hence, a mask whose energy concentrates on the low SF band, for instance a noise made of large elements, should mainly affect the corresponding range of target SFs (i.e. those conveying its global shape). Another mask whose energy is greater on higher SFs, for instance a pattern, should disrupt more efficiently the information conveyed by smaller details of the target necessary to identification. In fact, a pattern must have a lot of energy on the medium to high SF range as it is a random distribution of target details. Thus, its larger impact on target identification should mainly result from its increased energy on medium to high SFs, not from a higher level of target processing being specifically disrupted as proposed by Turvey (1973). Then, it is possible that the same low level mechanisms are involved by a noise or a pattern but that these mechanisms are more or less involved according to the mask energy on the critical SF information. Moreover, if two tasks require processing of two distinct SF ranges of the target and if two masks have opposite energy distributions on these two SF ranges, an interaction between mask and task should be observed.

Two experiments were run to test these assumptions. In both, fragmented pictures of objects served as targets and the same four masks were used. Three of them were noises composed of elements varying in size (from 1 × 1 to 2 × 2 and to 4 × 4 pixels) identical with those classically used in the literature (see earlier). The other was a pattern composed of target fragments. Because our targets were already made of spaced fragments, the pattern was a random distribution of these fragments with the same spacing as in the target (minimum of one pixel between fragments). In that, this mask is quite different from the connected and overlapping letter fragments used by Turvey (1973) to mask letters. However, the two masks should count as patterns as, according to Turvey, they are structurally similar to their respective targets. If this were true, our pattern mask should disrupt performance through the pattern-specific, interruptive mechanism postulated by Turvey.

The subjects had to perform two different tasks: A global shape discrimination task (Experiment 1) which can rely mainly on the extraction of low SFs (Ginsburg, 1986; Hughes, Fendrich, & Reuter-Lorenz, 1990; Hughes, Lawton, Baird, & Lester, 1984), and a naming task which depends on processing of higher SFs (Experiment 2). Extracting the global shape of an object occurs prior to accessing its semantic content; hence, each of the two tasks relies on a different stage of processing (e.g. Boucart & Humphreys, 1992; Riddoch & Humphreys, 1987) as well as on different SF ranges of the target. Now, the distinction between a peripheral integration mechanism of masking and three central mechanisms of masking has first been postulated from results observed in the identification of single letters and trigrams (Michaels & Turvey, 1979; Turvey, 1973). However, one cannot assume that the low level processing involved in the discrimination of the target's global shape implies that all these mechanisms are involved (Michaels & Turvey, 1979). Indeed, a task effect has actually been reported by Breitmeyer (1984). He showed that the identity of a letter was suppressed by a noise mask over a longer temporal interval than the location information of this target and suggested that this was due to different temporal processing of the channels conveying these two types of information (relying respectively on the sustained and the transient information). Both masking effects were consistent with sensory level perturbations while higher order processes were involved in the naming task.

The aim of this paper is therefore to test the distinction between noise and pattern mechanisms of masking and to determine the level of processing the mask perturbs within each of the two. If the low level interactions between transient and sustained channels are sufficient to explain masking effects (Breitmeyer, 1984), examination of the energy distribution among their SF components should allow to predict masking effects. It is assumed that the masking efficiency of a meaningless structure, such as a noise or a pattern, should essentially result from the relative visibility (Bonnet, Brettel, & Cohen, 1989; Ginsburg, 1986) of the target SF bands insofar as this information is critical to the task. Namely, the difference between the two masks should be more quantitative than qualitative: A noise or a pattern mask should entail the same low level masking mechanisms whatever the level of target processing required by the task. The involvement of the low level masking mechanisms should depend on the mask energy on the critical spectral information. In addition, the efficiency of the mask should depend on the task insofar as the task determines the SF range critical for processing.

EXPERIMENT 1

The purpose of this experiment is to test the distinction between noise and pattern masks (Turvey, 1973) in a task involving the discrimination of the target global shape.

In order to control the level of processing reached by the target before the mask occurs, we used two versions of the target; one nameable and the other non-nameable. Extracting the global shape is realized during the first stages of visual processing, at least prior to the access to semantic and lexical representations (Riddoch & Humphreys, 1987). However, with suprathreshold stimuli, identification processes irrelevant to the task are automatically carried out, thereby increasing the RT for nameable targets, as was shown by Boucart and Humphreys (1992) with the stimuli to be used in the present study. Consequently, in the present experiment, finding a lack of difference between performance for nameable and for non-nameable targets would suggest that the stage of matching with high level representations is not reached, and, therefore, that the perturbation from the mask takes place at the early stages of target processing.

Masking was investigated in backward condition—the mask followed the target—with various interstimulus intervals (ISI) in order to observe masking functions that relate performance to ISI. These functions are expected to be monotonic because the energy of the target was lower than that of the mask (Breitmeyer, 1984; Turvey, 1973).

Insofar as masking effects were consistent with interactions between the early channels of visual processing (Breitmeyer, 1984), it is assumed that masking efficiency should be related to the energy content of the different masks on the specific SF range involved by the global shape discrimination task (i.e. the low SF band; De Valois & De Valois, 1988; Ginsburg, 1986), whether the mask is of the pattern or noise variety.

Method

Participants. Four observers well trained in psychophysical experiments participated in the experiment. One of them was the author. All participants have normal or corrected-to-normal visual acuity.

Stimuli. The targets were 24 fragmented forms derived from 12 outline drawings of objects (Boucart & Humphreys, 1992). There were six animals and six vehicles. In each semantic category half of the forms were "oval" (the main axis of the shape was horizontal) and three forms were "round" in shape. Examples of oval and round forms are displayed in Figure 1. The use of fragmented forms is justified by the fact that it provides an easy way to generate two versions of the stimuli, one nameable and one non-nameable, while keeping their global shape constant. Twelve forms were nameable and the other twelve non-nameable. For nameable pictures the fragments were aligned on the virtual contour. In the non-nameable version the fragments were rotated in order to reduce their collinearity. The nameability of the two types of forms, observed

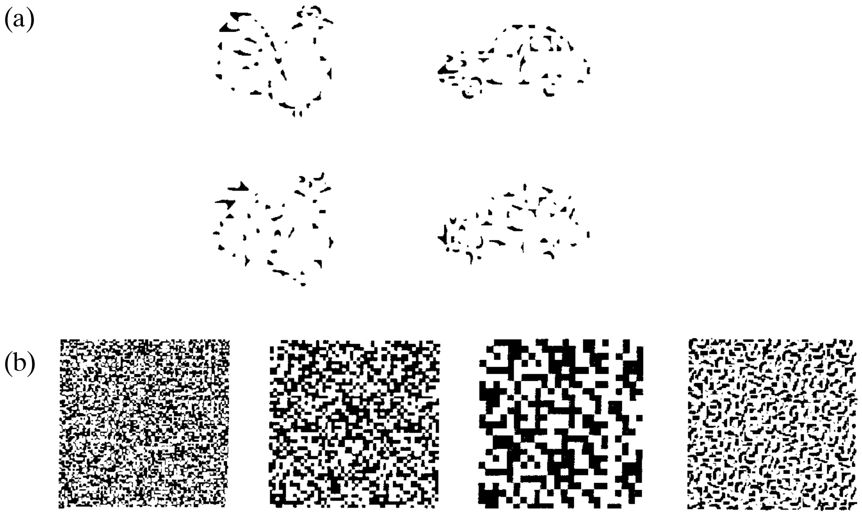

FIG. 1. Stimuli presented in Experiment 1, represented here at opposite contrast—in the experiment, figures were dark on a grey background. (a) examples of targets: A round animal (cock) and an oval vehicle (car), with their non-nameable versions below; (b) examples of the four types of mask: Respectively, Noise 1, Noise 4, Noise 16, and the pattern mask.

in Boucart & Humphreys (1992) was 73.7% for nameable forms and 13.2% for non-nameable forms. On average, the horizontal × vertical size was 2.6° (SD = 0.05) × 1.6° (SD = 0.11) for the oval targets and 2.0° (SD = 0.10) × 1.8° (SD = 0.05) for the round ones.

Four types of mask (see examples in Figure 1) were used. The three noise masks varied in the size of their elements (1 × 1, 2 × 2, and 4 × 4 pixels for Noise 1, Noise 4, and Noise 16, respectively). The elements were randomly distributed in a 100 × 100 pixel matrix. They covered 50% of the surface of the mask. The pattern mask was composed of a random distribution of target fragments. Three exemplars of each mask were built. They were randomly presented from trial to trial. Each mask covered 2.7° horizontally and 2.7° vertically.

SF Description of the Stimuli. The predictions are based on the estimation of the mask energy on the critical SF band: The more energy the mask has on that information, the more it should perturb the extraction of the corresponding information in the target. Conversely, the more the target has energy on that SF band, the less it should be masked.

The two-dimensional Fourier transform of each stimulus was computed from the 128 × 128 pixel matrix[1] of the black and white images using the Fast Fourier Transform algorithm (e.g. Bracewell, 1965/1986). The power spectral density of an image (squared amplitude spectrum) provides a measurement of the energy of each SF component (its power), irrespective of phase (e.g. De Valois & De Valois, 1988). The power (P) of each SF component of the spectra was computed by multiplying the complex number resulting from the Fourier transform, $f = a + bi$, by its complex conjugate, $\mathrm{conj}(f) = a - bi$, and dividing the result by a constant, 128^2:

$$P_f = \frac{f \times \mathrm{conj}(f)}{128^2}$$

The percentage of energy conveyed by a determined SF range was obtained by calculating the sum of the powers of each SF-component energies belonging to that particular SF range divided by the sum of all the SF-component powers

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[1] The masks, the round and oval targets were respectively matrixes of 100 × 100, 80 × 80, and 64 × 100 pixels. A matrix of 128 × 128 pixels is better adapted for 2D-FFT computation. Moreover, it gives frequencies in the range +/– 18.5cpd with a step of 0.29cpd. The targets were put unmodified into a 128 × 128 pixel matrix, which implies that their global shape is taken into account in the computation. It is not desirable that the global shape of the mask were taken into account as it is constant for each mask. To avoid this, the blank space left by each mask in the 128 × 128 pixels was filled with corresponding elements. By doing this, the masks are considered as arrays of small elements rather than big (100 × 100 pixels) squares made of small elements, which would have increased the energy on low SFs.

of the entire spectra (except the DC component, or zero-SF, which corresponds to the mean luminance of the image). For the global shape discrimination task, only the low SF components of less than 1.5cpd were taken into account.

SF estimations are summarized in Table 1. Fragmented forms of objects used as targets had on average 12.1% (SD of 1.4) of their energy conveyed by the low SF band: It corresponds to the sum of the low SFs powers (42.2) divided by the sum of all SFs powers (341.2). Nameable and non-nameable targets had about the same energy distribution. In fact, the rotation of the fragments which was used to generate the non-nameable figures from the nameable ones had little effect on the energy distribution: For example, 12.0% and 12.1% of the energy is conveyed by the SF less than 1.5cpd. The fragment rotation should rather affect the phase spectrum which was not taken into account here. However, manipulating the global shape of the target (round vs. oval) led to different distribution of energy, which concentrates on the horizontal low components for the oval targets (6.0% of the energy on the horizontal axis against 3.1% on the vertical one), whereas, for the round ones, energy was almost equally distributed on these two orientations (4.7% on the horizontal axis and 4.4% on the vertical one). Nevertheless, when all orientations were taken into account, the percentage of energy on low SFs was almost equal for round (mean of 11.6%) and for oval targets (mean of 12.6%). Hence, no differential masking effect was expected for the four types of target.

On average, the masks had only 6.3% of their energy distributed on the low SF range. It represented a larger absolute value than the one found in target as the sum of powers in the masks' entire spectra (mean of 4056, SD of 68) is around 12 times the corresponding sum in the target spectra. Contrary to what happened for the targets, important differences were found among the spectral power density of the four masks. The energy of the Noise 1 mask was evenly distributed among all SF components of the spectrum. When the size of the noise element increased and because large size aleatory configurations emerged, the energy distribution became less homogenous; it concentrated on lower SF components (for SF less than 1.5cpd: 1.4%, 5.0%, and 15.2% for Noise 1, Noise 4, and Noise 16, respectively). Our pattern mask whose fragments had energy mainly concentrated on the medium to high SF range (3.4% on SF less than 1.5cpd). Insofar as this SF range is involved in the global shape discrimination task, differential masking effects were expected for the four masks. Following the estimations summarized in Table 1 for SFs less than 1.5cpd, the noises should provide progressively more masking as their element size increases and the pattern mask should be less efficient than the two noises made of larger elements.

Apparatus. The stimuli were presented binocularly on a black and white video monitor. They were generated through an IBM compatible computer (Hewlet-Packard VECTRA QS20) equipped with a graphic card (VGA

Table 1
Mean Percentage of Energy Found on SFs Less Than 1.5cpd for the Four Target Types and the Four Masks in Experiment 1

	Stimuli							
	Targets				*Masks*			
SF band	*N-O*	*N-R*	*NN-O*	*NN-R*	*Noise 1*	*Noise 4*	*Noise 16*	*Pattern*
SF < 1.5cpd	12.2	11.8	12.9	11.4	1.4	5.0	15.2	3.4

N = nameable; NN - non-nameable, O = oval, and R = round.

Trident) with a resolution of 640 × 480 pixels (VGA Hi) at 60Hz frame rate (non-interlaced). At a viewing distance of 70cm enforced by a chinrest, the angular size of one pixel was 0.027 × 0.027 degree of visual angle. Careful calibration of each R-G-B combination was performed with a Minolta CS100 photometer which had been cross-checked with another device standardized to a Pritchard photomultiplier.

Both targets and masks were displayed in black on a grey background ($7.08cd/m^2$). Their respective luminance was of $4.95cd/m^2$ and $0.104cd/m^2$, which correspond to Michaelson contrasts of 17.7% for targets and 97.1% for masks. The grey background served both as fixation and as ISI fields. Preliminary trials were run to determine the luminance of the target and the mask to be used in the experiment itself. The lower contrast of the target relative to the mask was chosen to provide a sufficient amount of masking. Moreover, on the basis of a preliminary experiment in which we tested the discriminability of the oval and the round forms, we ensured that with such a contrast value the global form of the targets was perfectly discriminable provided no mask was presented. In this preliminary experiment, the 24 unmasked targets were presented five times with a duration of 33msec. Subjects were asked to respond to the global shape of the form by pressing one of two response keys. The subjects were the same as those who took part in the main masking experiment. The correct response rate averaged over the four subjects was 97.1%; hence, the shape of the unmasked stimuli was perfectly discriminable.

Procedure The temporal sequence of a trial was the following. A central fixation point appeared for 500msec together with a warning tone. Then, a fragmented form was presented for 33msec (two frames). After a variable ISI of 17, 33, 50, 66, 83, or 100msec, the mask was displayed for 100msec (six frames). The task was to decide whether the target had a round or an oval global shape. Subjects responded by pressing the left key for a round target and the right key for an oval one. The next trial was initiated 2000msec after the response.

There were four different experimental blocks of 144 trials each (24 targets × 6 ISIs), one corresponding to each mask. Within each block, the 24 targets and the 6 ISIs were randomly presented. The four blocks were repeated once. The order of the blocks was randomized within each repetition.

Performance was measured in terms of percentage of correct responses and of response time (RT). Only accuracy was stressed but subjects were informed that response latency was also recorded. Errors were indicated by a centrally displayed message. These trials were not replaced. A session comprising 48 trials for each type of mask was given as practice.

Results

The results are displayed in Figure 2. Two analyses of variance were conducted, one on the percentage correct and one on the average of the median RT. There were four within-subject variables: (1) target nameability, (2) target global shape (round vs. oval), (3) mask type (Noise 1, Noise 4, Noise 16, pattern), and (4) ISIs (17, 33, 50, 66, 84, and 100msec). The mean percentage of correct response was 79.0% and the mean RT was 646msec.

Percentage correct. There was no significant main effect of target nameability, 80% vs. 78% for nameable and non-nameable targets, $F(1, 3) < 1$, nor of the global shape, 84.2% vs. 75.6% for the oval and round targets, $F(1, 3) = 5.813$, ns.

Performance was affected by ISI, $F(5, 15) = 45.252$, $p < .05$. Accuracy increased as the delay between target and mask increased: 65.5%, 65.3%, 77.4%, 85.7%, 92.8%, and 93.6% for ISI of 17, 33, 50, 66, 84, and 100msec, respectively. The linear regression of the mean masking function (averaged over subjects and masks) showed that the increase in accuracy was monotonic with the increase of ISI, $r = 0.98$, $p < .01$. Performance was also affected by mask type, $F(3, 9) = 4.308$, $p < .05$. Accuracy was lower for the two noise masks made up of large elements (75.4% and 78.8% for Noise 16 and Noise 4) than for the pattern mask (81.1%), and Noise 1 (84.4%) was the less efficient mask. A paired comparison (Newman-Keuls) was carried out. Significant differences were found between Noise 16 and Noise 1, $F(1, 9) = 15.7$, $p < .05$, Noise 1 and Noise 4, $F(1, 9) = 7.9$, $p < .05$, and between the pattern and Noise 16, $F(1, 9) = 8.37$, $p < .05$. These analyses showed that Noise 16 is more efficent than Noise 1 and the pattern mask, but as efficient as Noise 4. Noise 4 is more efficient than Noise 1, but did not differ from the pattern mask. Lastly, the efficacy of Noise 1 and of the pattern mask did not differ significantly.

There was no interaction between mask type and ISI, $F(15, 45) < 1$. The slope of the masking function for the pattern mask, 0.45 after linear regression on percentage correct relative to ISI, $r = 0.98$, $p < .005$, was descriptively higher than those of the noise masks: For Noise 1, 0.32, $r = 0.94$, $p < .01$; for Noise 4: 0.41, $r = 0.96$, $p < .01$; and for Noise 16: 0.42, $r = 0.94$, $p < .01$. However, this difference did not reach significance.

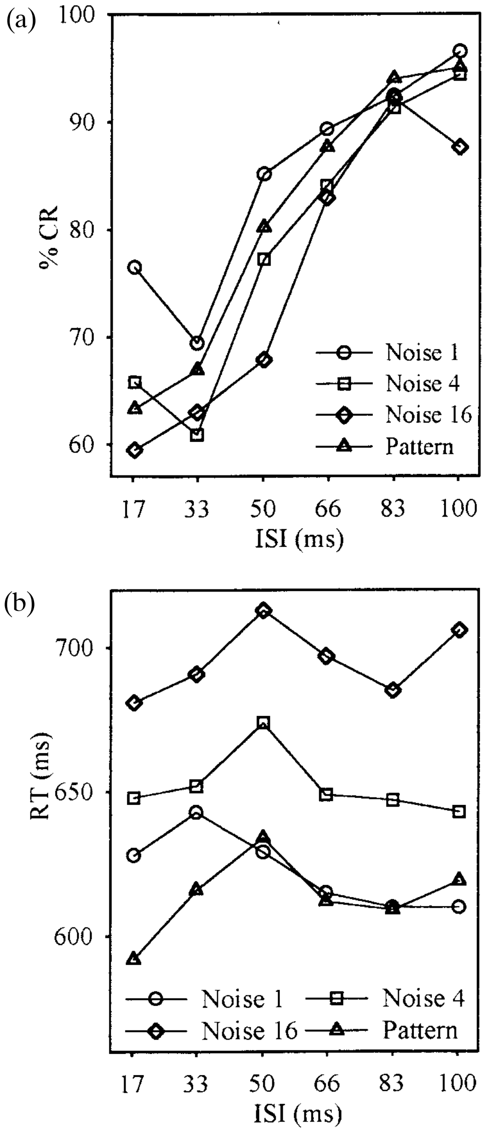

FIG. 2. Results for Experiment 1: (a) the percentages of correct responses as a function of ISI for each type of mask; (b) corresponding mean response times.

Target global shape interacted with mask type, $F(3, 9) = 15.319, p < .001$, and with ISI, $F(5, 15) = 3.435$, $p < .05$. The three-way interaction between global shape, mask type, and ISI was also significant, $F(15, 45) = 2.939$, $p < .05$. Planned comparisons showed that global shape affected significantly the discrimination only for the most strained experimental conditions; that is, both for the shorter ISIs and for Noise 4 and Noise 16 masks: ISI of 17msec, oval: 77.2%, round: 48.2%; ISI of 33msec, oval: 78.2%, round: 45.8%; $F(1, 3) = 16.62$, $p < .05$. In the other conditions (that is, for Noise 1 and for the pattern mask and for ISIs of 50, 66, 83, and 100msec, no significant effect of global shape was found, $F(1, 3) < 1$. In fact, most of the response matrices showed an asymmetry due to an unbalanced distribution between oval and round responses. Consequently, the present data were analysed using the A′ statistics (Aaronson & Watts, 1987; Pollack & Norman, 1964), which express sensitivity by taking the whole data matrix into account. Such an index corrects the asymmetry between the two responses. The main conclusion of the analysis remained the same on that index (Table 2). The response bias was estimated by the B″ statistics which showed that the opposite bias was observed for the pattern mask than for the noise masks and that the response criterion was almost the same whatever the ISI, as shown in Table 2. In fact, the round against oval global shape discrimination is a task that could induce some response bias, because there is no a priori evidence that the two shapes are equally identifiable. As a matter of fact, as indicated by SF estimations, the energy content on low SF band was slightly higher for the oval targets (mean of 12.6%) than for the round ones (11.6%). Therefore, a convenient strategy for the subject is to favour the more easily perceived form, especially when the experimental conditions are very strained. Yet, the A′ statistics showed that although the response bias affected the magnitude of the effects of ISI and mask type, the order of the results according to their modalities remained unmodified.

Response Time. None of the experimental variables had an effect on the response time (RT) data. RTs did not vary with the delay between target and mask: 637, 650, 661, 640, 630, and 641msec for ISI of 17, 33, 50, 66, 84, and 100msec, respectively, $F(5, 15) < 1$. RTs were not affected by the mask type: 622, 650, 695, and 614msec, for Noise 1, Noise 4, Noise 16, and pattern mask, respectively, $F(3, 9) < 1$. Performance was equivalent for nameable and non-

Table 2
Mean Effect of Mask Type and ISI in Experiment 1 Expressed by A′ and B″ Indexes

	Mask Type				*ISI (msec)*					
	Noise 1	*Noise 4*	*Noise 16*	*Pattern*	*17*	*33*	*50*	*66*	*83*	*100*
A′	0.91	0.87	0.85	0.88	0.74	0.74	0.86	0.92	0.96	0.97
B″	0.23	0.23	0.33	−0.21	0.09	0.13	0.19	0.15	0.19	0.09

nameable targets: 646msec each, $F(1,3) < 1$, and for oval and round forms, 646 vs. 645msec, $F(1,3) < 1$.

Discussion

There were three main results. First, two noise masks (Noise 4 and Noise 16) were more efficient in terms of masking than the pattern mask. Second, all the masking functions were monotonic and their slopes did not differ. Third, there was no effect of target nameability.

The mask effects found in the present experiment are inconsistent with the existence of the two different mechanisms of masking postulated by Turvey (1973). According to this author, a noise mask operates only through integration of the peripheral information conveyed by both the mask and the target, without any contribution from later interruptive mechanisms. With short ISI, a pattern mask operates the same way, although more strongly than a noise mask (see Turvey, 1973, Figure 12). With longer ISI, the target has evaded the influence of the peripheral energy integration mechanism whereas the central pattern-specific interruptive mechanism becomes the unique cause of the masking effects. In 1973, Turvey assumed that peripheral integration and central interruption correspond to two successive stages of processing, the latter being initiated only after the former was completed. Although appealing, this model cannot account for the masking effects observed in the present experiment. The reason is that the pattern mask was less efficient than two of the noise masks (Noise 4 and Noise 16), whatever the ISI. This runs contrary to Turvey's theory because, if the integration and interruption mechanisms were all involved in the global shape discrimination task, masking should be stronger for the pattern than for any of the noise masks, especially for the longer ISIs. If, on the other hand, only the energy-dependent integration mechanism were responsible for the observed effects whatever the mask (as one can argue because of the low level of processing needed by the task), the pattern should nevertheless cause more masking than any of the noise masks. If, as mentioned at the end of the introduction, our pattern mask does conform to Turvey's intuitive definition in terms of structural similarity with the target, then the pattern-specific interruptive mechanism should be operative. Hence, the present results are inconsistent both with the existence of a single integration mechanism responsible for masking with any mask, and with the existence of a later interruption mechanism involved only in pattern masking.

Rather than postulating a stage model as Turvey (1973) did, one can predict and explain the results of Experiment 1 much better by simply relying on spectral analyses of the masks. Indeed, masking efficiency varied according to mask energy on low SF bands: The more energy the mask has on this range, the more impaired the discrimination of the target global shape was. Such a result is consistent with low level interactions between target and mask processes, as proposed in Breitmeyer's masking model (1984).

Another result that attests of the low level of the mask perturbation involved in the present experiment is that target nameability has no effect on the discrimination between the forms. This implies that contrary to what happens with unmasked stimuli, the access to the semantic and lexical representations is prevented by the mask. This is because when it is not prevented, and even though it is irrelevant to the task, responses involving global discrimination are longer for nameable than for non-nameable targets (Boucart & Humphreys, 1992). Hence, the absence of a target nameability effect in the present experiment further indicates that processing does not reach the level of semantic representation. The highest processing level at which the hampering effect of the mask could take place is therefore that of structuring processes of the target.

EXPERIMENT 2

Experiment 1 showed that for a task that can already be performed on the basis of early stages of processing, the masking effect was early too. The question raised in Experiment 2 is whether this conclusion could be extended to a case in which higher order, later processing stages are involved; namely, in picture naming. Compared to global shape discrimination this task requires several additional stages of processing: Supplementary structuring processes, such as encoding of the target contour, and access to the stored information in memory. If masking happens to be low level visibility effects even when these higher stages of target processing are involved, then the SF content of the stimuli should once again predict masking efficiency.

Target contour information required for identification is conveyed by medium to high SFs (Ginsburg, 1986; Harmon & Julesz, 1973). If the energy content of the four masks on the corresponding SF ranges varies, they should differentially affect encoding of the target contour.

In order to check the level of processing achieved by the target before the perturbation from the mask, an analysis of errors was performed on the results. The semantic category of the target was manipulated. In fact, if the mask interferes with late target identification processes, representations of the objects belonging to the same semantic category should be activated, which could generate an excess of semantic errors; that is, responses belonging to the target semantic category. Conversely, if the mask operates prior to the access to high level representations, no excess in semantic errors is expected.

In this experiment, both a forward (mask before target) and a backward (target before mask) masking conditions were used. Each condition involved four different ISIs. Because the energy of the target was lower than that of the mask (the luminance of target and mask were the same but the duration of the mask was longer), the masking functions are expected to be monotonic, as in Experiment 1. The rationale for using both forward and backward masking is that they entail different masking mechanisms (Breitmeyer, 1984; Turvey, 1973). If the peripheral mechanism prevails, forward masking effects should be stronger and should last longer than backward masking. The opposite should be true if the central mechanisms are dominant (Turvey, 1973).

Method

Participants. Four subjects took part in the experiment. Two of them participated in Experiment 1. The two less-trained subjects got an additional practice session. All subjects had normal or corrected-to-normal vision.

Stimuli. The targets were 20 fragmented forms of objects belonging to four semantic categories: (1) animals, (2) vehicles, (3) tools, and (4) pieces of clothing. The global shape was oval for all stimuli. The target mean angular size was 1.8° (SD = 0.09) of visual angle horizontally and 1.35° (SD = 0.15) vertically. The viewing distance was 70cm. The four masks were the same as those used in Experiment 1. To ensure agreement in target naming, the participants were familiarized with the stimuli before the experiment began.

A preliminary experiment was conducted to estimate the nameability of the unmasked targets. Naming thresholds were established through an ascending method of limit in which the contrast was increased until the target was correctly named. This procedure was repeated five times for each of the 20 pictures, thereby yielding five threshold estimates for each picture. The results showed that all pictures were correctly named below a contrast of 15% (mean of 12.2%). The threshold values, which were within the same range for all subjects, constituted a lower limit for the luminance levels manipulated in the second preliminary experiment.

The aim of the second preliminary experiment was to determine the level of luminance of both the target and the mask needed for reaching about 70% of correct naming responses. The constraint was that the contrast of the mask was equal to that of the target[2] rather than higher as in Experiment 1. Finally, the contrast to be used in the main experiment was 25.9% corresponding to a luminance 4.17cd/m^2.

SF Description of the Stimuli. Medium to high spectral components (SFs from 1.5cpd to 9cpd) were taken into account as this SF band is assumed to

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[2] Because it was shown that an increased luminance for the mask relative to that of the target induced an asymmetry between forward and backward condition for noise masking (Turvey, 1973, Experiment XV).

convey the information necessary for identification. The target energy was quite the same for the four semantic categories (55.5%, 55.2%, 57.1%, and 57.5% for animals, vehicles, tools, and pieces of clothing, respectively). Hence, no differential masking of the four types of target was expected.

SF estimations are summarized in Table 3. Contrary to that of the stimuli, the energy of the different masks within the critical SF band varied. The pattern mask had the greatest energy (75.8%); the energy of the noise masks decreased as the element size decreased (69.5%, 55.6%, and 26.7%, for Noise 16, Noise 4, and Noise 1, respectively). Insofar as early interactions between SF channels are involved in the task, there should be a direct relationship between masking efficiency and mask energy.

Apparatus. The apparatus was the same as that used in Experiment 1 except that subjects responded in a microphone connected to a voice key.

Procedure. Two masking conditions (forward and backward) were used. A fixation point was displayed for 500msec. It was followed by a first stimulus that was a picture, centrally displayed for 17msec (in the backward condition), or a mask, presented for 50msec at the same spatial location (in the forward condition). After a variable interval (ISI of 17, 33, 50, or 66msec), the second stimuli was presented. This second stimulus was a mask in the backward condition and a picture in the forward one. The duration of the mask was shorter in Experiment 2 than in Experiment 1 (50 vs. 100msec) to compensate for the increased difficulty of the naming task compared to global shape discrimination. However, the target/mask duration ratio was equivalent in both experiments. In addition, the durations chosen were long enough to involve both the peripheral and central masking mechanisms (Turvey, 1973). Subjects were asked to name the target. They were encouraged to guess and to respond by saying "nothing" if they could really not identify the picture. The intertrial interval was fixed at 2500msec.

The experiment comprised two sessions of four blocks each (i.e. 1280 experimental trials). Each block contained 160 trials (20 targets × 8 ISIs: –66, –50, –33, –17msec in forward masking and +17, +33, +50, and +66msec in

Table 3
Mean Percentage of Energy Found on SFs from 1.5cpd up to 9cpd for the Four Semantic Categories of Target and the Four Masks in Experiment 2

	Stimuli							
	Targets				*Masks*			
SF band	*Animal*	*Vehicle*	*Tool*	*Clothes*	*Noise 1*	*Noise 4*	*Noise 16*	*Pattern*
1.5 < SF < 9cpd	55.5	55.2	57.1	57.5	26.7	55.6	69.5	75.8

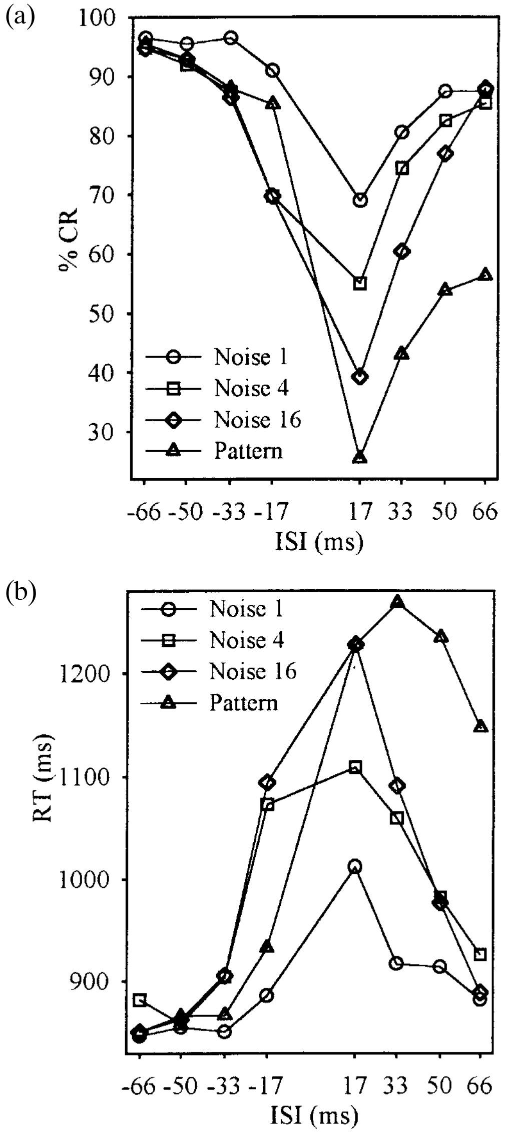

FIG. 3. Results for Experiment 2: (a) the mean percentage correct; (b) the corresponding mean response time, both as a function of ISI and mask.

backward masking). The target appeared randomly. The four masks were tested in separate blocks. The order of the blocks was different for each subject. Prior to the experimental part, the two naïve subjects were given a practice session of 180 trials for each type of mask. Naming accuracy was measured by percentage correct. Response latency was recorded, without any explicit instruction about speed.

Results

The main results are presented in Figure 3. Two analyses of variance were conducted, one on the percentage correct and the other on the medians of RT. There were three within-subject variables: Target semantic category, ISI, and mask type. The mean percentage correct was 78.0% and the mean RT was 973msec. The response “nothing” was given on 5.7% of the trials.

Target semantic category had no significant effect on percentage correct: 81.6%, 77.6%, 73.7%, and 81.2%, for animals, vehicles, tools, and pieces of clothing, respectively, $F(3, 9) = 1.9$, ns; or on RT: 964, 986, 995, and 951msec, for animals, vehicles, pieces of clothing, and tools respectively, $F(3, 9) = 2.5$, ns.

Accuracy increased and RT decreased as the ISI increased, $F(7, 21) = 19.62$, $p < .001$ and $F(7, 21) = 12.01$, $p < .001$, both in condition of forward masking: 79.2%, 89.8%, 92.7%, 95.6% and 996, 882, 860, 857msec, for ISIs of –17, –33, –50, and –66msec, respectively, $F(3, 9) = 17.41$, $p < .001$ for percentage correct, and $F(3, 9) = 9.14$, $p < .001$ for RT; and backward masking: 47.7%, 64.7%, 74.9%, 79.5% and 1114, 1083, 1027, and 961msec for ISIs of +17, +33, +50, and +66msec, respectively, $F(3, 9) = 42.11$, $p < .001$ for percentage correct, and $F(3, 9) = 9.14$, $p < .001$ for RT.

Performance was affected by mask type, $F(3, 9) = 8.34$, $p < .01$ for percentage correct and $F(3, 9) = 9.24$, $p < .01$ for RT. The masking efficiency of the noise masks increased as the size of their elements increased (in order, 87.9%, 80.2%, and 76.1% for Noise 1, Noise 4, and Noise 16), and the pattern was the most efficient (67.5%). RT varied inversely with accuracy: RT increased as the size of noise elements increased, and the longest RT was found for pattern mask (in order, 895, 974, 987, and 1049msec for Noise 1, Noise 4, Noise 16, and the pattern).

The type of mask interacted with masking condition (forward vs. backward) both on accuracy, $F(21, 63) = 8.22$, $p < .001$, and on RT, $F(21, 63) = 4.12$, $p < .001$. As can be seen in Figure 3, making effect occurred mainly in the backward conditions (ISI of +17, +33, +50, +66msec) for percentage correct: 81%, 74.4%, 66.2%, 44.6%, for Noise 1, Noise 4, Noise 16, and pattern, respectively, $F(3, 9) = 14.48$, $p < .001$, and for RT: 931, 1019, 1046, and 1219msec, for Noise 1, Noise 4, Noise 16, and pattern, respectively, $F(3, 9) = 14.03$, $p < .001$. No effect of type of mask was found in forward masking condition, either on percentage correct: 94.8%, 86%, 86%, and 90.4%, for Noise 1, Noise 4, Noise 16, and pattern, respectively, $F(3, 9) = 3.18$, ns, or on RT (859, 929, 928, and 879msec, for Noise 1, Noise 4, Noise 16, and pattern, respectively, $F(3, 9) = 3.18$, ns.

A descriptive analysis of the type of errors was conducted. An error was classified as *semantic* when the named concept belonged to the same semantic category as the target (for example, the response "hammer" for "saw"). It was called *non-semantic* when the named concept was from a different semantic category (for example, the response "hat" for "ship"). The "nothing" responses (mean of 5.7%) were not taken into account in this analysis. On average, non-semantic errors (10.1%) prevailed relative to semantic errors (6.2%). The proportion of non-semantic errors relative to semantic errors was more important in the backward masking condition (7.6% vs. 4.5%) than in the forward masking condition (2.5% vs. 1.8%). As shown in Figure 4, in the backward masking condition the number of non-semantic errors was higher than the semantic errors for shorter ISIs (up to 50msec for the less efficient masks—Noise 1 and Noise 4—and up to 66msec for the most efficient masks—Noise 16 and pattern). The number of the two error types reversed for longer ISIs.

Discussion

There are three main results: First, the type of mask has an effect on identification performance; second, masking functions show an asymmetry between forward and backward conditions; and third, the proportion of semantic errors varied depending upon masking magnitude.

Mask efficiency is closely related to the mask spectral content, insofar as only the information relevant to the task is taken into account. The stronger masking effect is observed for the pattern mask whose energy on medium to high SF content is the greatest compared to the other masks. When energy on the SF band decreases, that is to say, when the size of the noise elements decreases, masking becomes progressively weaker. Such a result is in part consistent with the noise/pattern distinction (Turvey, 1973) since the pattern is more efficient than any noise.

The second result is more difficult to reconcile with Turvey's (1973; Michaels & Turvey, 1979) account of visual masking. In this theory, the advantage of the backward relative to the forward condition reflects the participation of two central masking mechanisms (target iconic inhibition and icon read-out), which are specific of backward masking. The fact that the forward/backward asymmetry is found for each of the four masks suggests that central masking mechanisms are involved, whether the mask is a pattern or a noise. Thus, the existence of a pattern-specific interruptive masking mechanism is not corroborated by the present results.

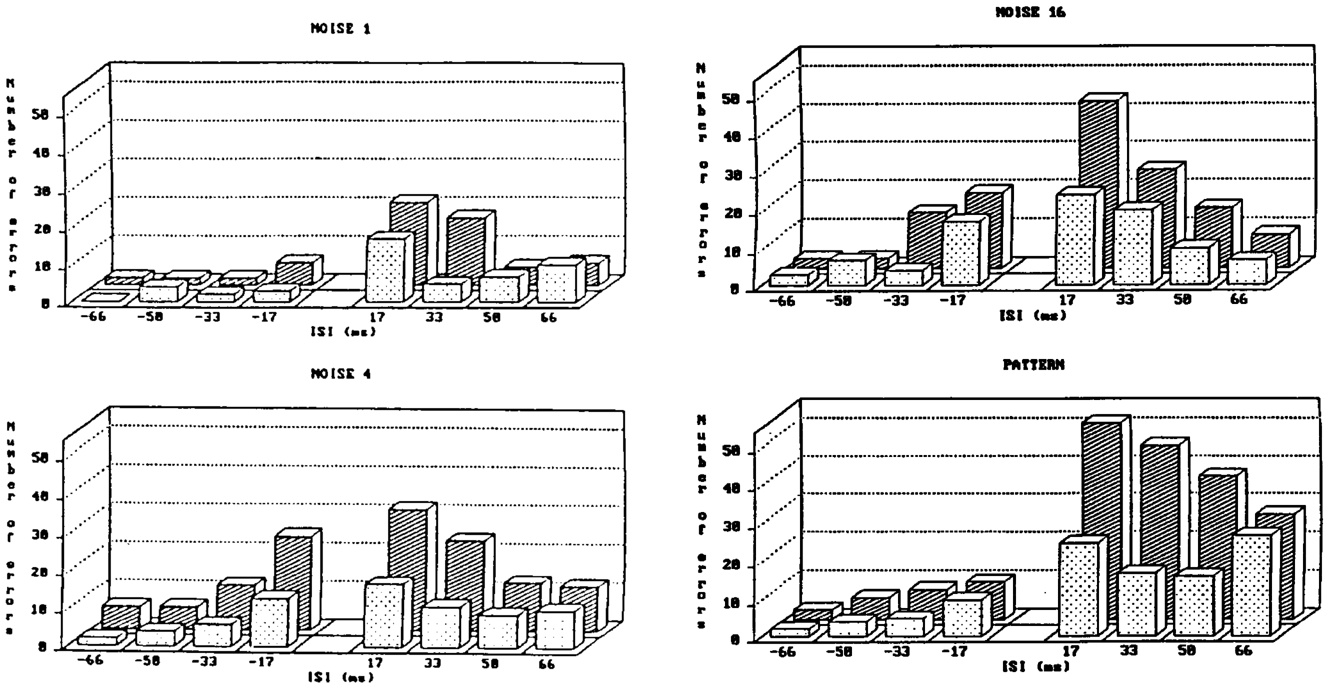

FIG. 4. Analysis of errors observed in Experiment 2, showing the number of errors as a function of ISI in condition of forward masking (i.e. the negative values of ISI) and of backward masking (the positive ones) for a particular mask; the dotted bars present the semantic errors and the hatched ones show the non-semantic errors.

In contrast, the present findings are consistent with the existence of early masking mechanisms which could account for both noise and pattern masking effects. Indeed, according to Breitmeyer's model (1984), backward masking should be stronger and should extend over longer temporal intervals than forward masking, for the following reasons. In forward masking, the sustained activity of the mask is centrally inhibited by the transient activity of the target (i.e. through the interchannel inhibition mechanism), which entails that the later cortical integration of the mask weakened sustained activity with that of the target (i.e. through the intrachannel integration mechanism) further favours the target over the mask. In backward masking, it is the sustained activity of the target that is inhibited by the transient activity of the mask. In addition, because the mask sustained activity remains unhampered by the target sustained activity, the intrachannel integration mechanism favours the mask over the target. Therefore, the sustained activity of the target underlying identification, is more perturbed in backward than in forward masking.

Such a target/mask order effect is classically observed (review in Breitmeyer, 1984) in conditions of dichoptic masking (target and mask are each presented to a different retina) in which peripheral interactions between the target and the mask cannot take place. When the peripheral interactions are combined with the central ones (in monoptic or binocular presentation), symmetrical forward and backward masking functions are generally observed. This is because peripheral masking effects which are more severe in the forward than in the backward condition are obscuring the interchannel inhibition mechanism, which is specific of backward masking (Breitmeyer & Ganz, 1976). Hence, with the binocular presentation used in the present experiment, the observed asymmetrical masking functions witness the privileged participation of the interchannel inhibition mechanism. To conclude, the observed forward/backward asymmetry between the masking functions strongly suggests that early interactions between SF channels account for masking by both noise and pattern masks.

An additional finding supporting the preceding conclusion is that there is no excess in semantic errors in the stronger masking conditions whereas such an excess is found in the weaker ones. A possible interpretation of this finding is as follows. According to Rosch, Mervis, Gray, Johnson, and Boyes-Braem (1976), there is often a high correlation between the structural similarity and the semantic similarity of objects belonging to the same semantic categories (for example, fruits often have a rounded shape). If this is true, one can expect that already because of their structural similarity with the target, objects belonging to the same category have their semantic and lexical representations automatically activated (see Humphreys & Riddoch, 1987, for evidence relating to this point). This entails that semantic errors can eventually arise from structural processing alone, particularly from contour extraction (Boucart, Delord, & Giersch, 1994). Therefore, if masking is early enough to prevent structural processing of targets, no such semantic errors could arise, which is indeed what is observed (see Figure 4) in backward masking for ISI below 50msec for the less efficient masks (Noise 1 and Noise 4) and below 66msec for the most efficient ones (Noise 16 and pattern). If, on the other hand, masking does not prevent structural processing, an excess of semantic errors is expected, which is the case when masking is weaker. Hence, once again, it looks as if masking takes place no later than the early stage of target contour processing, whether the mask is a pattern or a noise.

GENERAL DISCUSSION

Previous psychophysical studies on visual masking suggested that low level visibility effects are sufficient to account for the phenomenon. However, these studies used masks that were filtered on specific SF bands. Generally, when non-filtered masks were used to explore visual masking, authors are keeping with an information processing point of view and put forward higher masking mechanisms interfering with target icon formation. Because such classical masks could nevertheless have different energy distribution on their spectra, they must involve, at least in part, the same masking mechanisms as the filtered masks. The aim of the present study was thus to examine to what extent the early mechanisms affecting target visibility can account for the masking effects provoked by meaningless, unfiltered structures generally called noise and pattern masks.

The present study shows that: (1) masking efficiency of both noise and pattern masks are closely related to their energy on the spectral components conveying the information most relevant to each particular task; and (2) semantic processing of the target can be prevented by both types of masks.

Consequently, the conceptualization of the structural aspects of visual masking on the basis of the qualitative distinction between noise and pattern masks is inadequate because it rests on too intuitive an estimate of the target/mask structural similarity. Such a view leads to oppose two types of masks that can actually operate through the same mechanism. Indeed, a continuity rather than a dichotomy between the masking effects caused by noise and pattern masks is revealed by the present data. In fact, in Experiment 1 dealing with the discrimination of the global shape of fragmented forms of objects, the pattern mask was found to be less efficient than two of the noise masks (i.e. Noise 4 and Noise 16). In Experiment 2, in which meaningful forms had to be identified, the noise masks of increasing element size came close to exerting as much detrimental effect as the pattern. Hence, the masks used in the present study are distributed themselves on a continuum, and the noise and the pattern masks used by Turvey (1973) probably lie close to the extremes of this continuum.

The term “pattern” is now used to refer to a variety of masks that do not necessarily share all the characteristics of a pattern as defined by Turvey (1973), that is, a random arrangement of target features. For instance, in priming studies, strings of typographical characters such as #### are generally considered as pattern masks for targets made up of letters. The problem with this implicit assumption is that it often entails that interruptive mechanisms of masking are assumed to play a dominant role. For instance, high level processes of the prime, such meaning extraction, are supported to be selectively interrupted by the pattern mask while earlier processing should remain unaffected. The results presented here are not consistent with this view. It appears that integration and inhibition between the mask and target activities right from the beginning of visual processing are responsible for the masking effect. Consequently, the target could no longer be described as an entity distinct from the mask.

Indeed, the observed masking effects are closely related to the spectral content of the mask corresponding to the SF components of the target conveying the information most relevant to the task. Hence, irrespective of the level of processing required by the task, masking effects probably result from perturbations of the early perceptual processes occurring prior to the access to higher level semantic and lexical representations. Hence, it appears that a mask should not be efficient *on its own*, but it should be efficient for a particular task, that is for a particular spectral information of the target. The interaction between masks and tasks found here may result from the fact that different SF ranges are involved, not necessarily from different levels of target processing being affected by the mask.

The assessment of masking efficiency made here is proposed as an initial operational approach that does not claim to be exhaustive. Further investigations are needed that will take the phase information into account (presumably involved by the intrachannel inhibition mechanism), and will include the temporal aspects of the various SF channels. For the time being, the present research shows that the SF description of the stimuli allows to account for the structural aspects of visual masking. It thus provides further support to the view that visual perception of meaningful objects is mediated and constrained by SF filters (Solomon & Pelli, 1994).

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