The roles of mask luminance and perceptual grouping in visual backward masking

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Visual backward masking is a commonly used technique in vision research and psychology. There are two distinct types of masking. Either masking is strongest for a simultaneous presentation of the target and the mask (A-type masking) or masking is strongest when the mask trails the target (B-type masking). To account for the two types of masking, a variety of explanations have been put forward that often rely on low-level features such as the target-mask energy ratio. However, recent studies have demonstrated that the global spatial layout of the mask is an equally important factor. Here, we investigated both factors jointly. Our findings show that both factors strongly interact with each other and that neither one alone can explain the results. This finding indicates that choosing a mask should not be taken lightly when masking is used as a tool to investigate properties of perception or cognition.

Keywords: visual perception, backward masking, spatial grouping


Introduction

In visual backward masking, a target is followed by a mask that impairs performance on the target (monographs; Bachmann, 1994; Breitmeyer & Ögmen, 2006). Although masking is a frequently used tool in many research areas such as linguistics, memory, and vision, there has not yet been a consensus about its underlying mechanisms. This lack of consensus includes the factors that determine at which temporal interval the mask has its strongest effect on the target. Intuitively, it might be expected that masking is strongest when the mask is presented simultaneously with the target and monotonically improves when the mask trails the target (A-type masking). However, this is not always the case. For some target-mask combinations, performance is most strongly impaired when the mask follows the target by a delay in the range from 20 to 100 ms (B-type masking).

B-type masking is often found with masks that do not spatially overlap with the target, so-called metacontrast masks. Metacontrast masks are not the types of masks typically used in applications of masking. Instead, pattern masks, which overlap spatially with the target, are used, mostly yielding A-type masking (but see Hellige, Walsh, Lawrence, & Prasse, 1979; Turvey, 1973). This A-type masking fits into many researchers’ implicit assumptions that increasing the delay between the target and mask allows more time for the target information to be processed. However, whether a given target-mask combination really yields A-type masking is almost never tested.

In addition to the spatial overlap of the target and the mask, the target-mask energy ratio is commonly proposed to determine whether masking is of A-type or B-type.
Energy is often defined as the product of the luminance or contrast of the target/mask and its duration, referred to in the following as LT-energy (Luminance X Time). Many studies found that high-energy masks in combination with low-energy targets yield A-type masking. B-type masking is more commonly obtained when lower energy masks and higher energy targets are combined (review Breitmeyer & Ögmen, 2006). In these studies, however, usually only the luminance of the mask is varied. In a general sense, energy may also be changed when, for example, the size of the mask is changed. We will refer to this kind of energy as the LTS-energy, i.e., a function of luminance/contrast, duration, and stimulus size.

Duangudom, Francis, and Herzog (2007) showed that the global spatial layout of a mask has a profound effect on its masking strength. In their study, participants were asked to indicate the offset direction (left/right) of a vernier target that was followed by one flanking line on each side of the vernier, i.e., a typical metacontrast mask. B-type masking occurred. When the number of flanks on each side was increased to six flanks, strong A-type masking occurred (even though this mask is also a metacontrast mask; see Figure 1a). The $2 \times 6$ flank mask contains the $2 \times 1$ mask. Hence, the shape of the masking function can be changed by global spatial manipulations. Interestingly, when the length of the $2 \times 6$ lines is increased, masking strength decreases—even though the LST-energy increased (Duangudom et al., 2007; for a similar effect with pattern masks, see Hermens & Herzog, 2007; Herzog & Fahle, 2002; Herzog & Koch, 2001). Clearly, low-level explanations fail to explain these effects. We proposed an account in terms of perceptual grouping processes. The idea is that when target and mask are grouped into a single perceptual unit, the features of the target are no longer accessible even though the target itself is visible as a part of the group (Malania, Herzog, & Westheimer, 2007). For example for an SOA of 0 ms, the vernier target fits nicely between the two arrays of 6 flanking lines (Figure 1a). Thus, the vernier plus the $2 \times 6$ metacontrast mask makes up a regular structure of 13 equally spaced, clearly visible, and identical lines except for the vernier offset which is hardly visible. When the SOA changes, temporal cues break this grouping and performance improves. Francis and Cho (2008) likewise argued that the integrated target and mask percept blocks access to the individual properties of the target. Under these conditions, A-type masking occurs regardless of the mask energy.

In summary, previous work has shown that stimulus energy (especially luminance) and spatial layout individually influence masking strength. In this study, we aim to establish how luminance and spatial layout jointly influence mask strength. For example, if the grouping hypothesis is true, then we should be able to identify situations where increases in mask luminance lead to a release from perceptual unitization and thereby lead to weaker masking. As will be seen below, our empirical studies were unable to demonstrate this prediction, and this failure has implications for theories of masking and the use of masking as tool to investigate other perceptual and cognitive properties.

**General materials and methods**

Stimuli were displayed on an X-Y display (Tektronix 608 or HP 1332A) controlled by a PC via a fast 16 bit D/A converter (1MHz pixel rate). The refresh rate of the display was set to 200 MHz. Target luminance was set at approximately 40 cd/m². Observers viewed the stimuli from a distance of two meters in a room dimly illuminated by a background light of about 0.5 lx.

In all experiments, a target vernier was presented in the center of the screen. The vernier consisted of two vertical line segments separated by a vertical gap of 1'. Each of the two segments was 10' long and about 0.5' wide. The lower vernier segment was offset horizontally either to the left or to the right with respect to the upper one. This horizontal offset direction was chosen at random on each trial. The

![Figure 1](http://jov.arvojournals.org/)

**Figure 1.** From metacontrast to pattern masking. Stimulus sequence of Experiment 1. A target vernier was presented in the center of the screen for 20 ms followed by either (a) a metacontrast mask or (b) a pattern mask. The mask was presented either simultaneously with the target (SOA = 0 ms) or it followed the target at a variable SOA as shown here. Observers had to indicate whether the lower vernier segment was shifted to the left or to the right by pressing one of two push buttons (here a left offset vernier is shown).
The task of the observer was to report the direction of the vernier offset by pressing one of two push buttons. A beep sounded whenever the observer indicated the incorrect offset direction of the target vernier. The offset size (the horizontal distance between the two vernier segments) was controlled by means of an adaptive staircase procedure (PEST; Taylor & Creelman, 1967), for which we used a starting offset size of 75 arc seconds. The threshold was determined as the offset size for which 75% correct responses were obtained. If the estimated threshold exceeded a pre-defined maximum value of 150 arc seconds (two times the starting value), we assigned a value of 200 arc seconds.

Masks consisted of aligned, i.e., non-offset, verniers. Figure 1 sketches the time course of a trial for two different types of masks. Both the target vernier and the mask were presented for 20 ms. In all experiments, we determined the masking function by presenting the mask at six different stimulus onset asynchronies (SOAs): 0, 20, 40, 60, 80, and 100 ms. In each block of 80 trials, only one combination of a mask and an SOA was presented. Thresholds were measured twice for each condition, and after presentation of all conditions, their order was reversed to counteract effects of fatigue and practice on the average data. The order of blocks within each condition was randomized for each observer.

Six students of the Ecole Polytechnique Fédérale de Lausanne (EPFL) and one of the authors (FH) participated. Observers were first given a few practice trials with just the vernier target, i.e., without a mask, until they achieved a 75% correct threshold for a vernier offset size below 20 arc seconds. Because we were interested in how the shape of the masking function changes as the spatial layout of the mask changes, we performed an initial selection stage with the one-flank metacontrast condition. Only participants who showed type B masking in this condition continued with further experiments. One participant was excluded at this stage so that data was available from the remaining six observers. Each student gave informed consent and was paid for his/her participation. Observers had normal or corrected-to-normal vision as confirmed by the Freiburg vision test (Bach, 1996). Participants had to reach a value of 1.0 (corresponding 20/20) in at least one eye to participate in the experiments.

**Methods**

In separate blocks, we presented the target vernier with one of five possible masks. A label will be used to indicate each mask. Of the two metacontrast masks, one had one aligned (non-offset) vernier on each side of the target position. This mask is given the label 1N_1N (Figure 2; ‘N’ for ‘Non-offset’). The underscore in the middle indicates that the middle position of the mask (where the vernier target is located) does not have a mask element. The other metacontrast mask had six aligned verniers on each side of the vernier (6N_6N; Figures 1a and 2). Duangudom et al. (2007) previously studied these two types of masks and found B-type masking for the 1N_1N mask and A-type masking for the 6N_6N mask.

Based on these metacontrast masks, we constructed two pattern masks by adding a single aligned vernier in the middle of these two metacontrast masks, thereby producing two homogenous gratings. Hence, the resulting masks either contained three aligned verniers (3N) or 13 aligned verniers (13N; Figure 1b). To investigate the effect of the central element by itself, we also tested the single central element as a mask (1N). We will call these masks pattern masks even though they do not fully overlap with the vernier because of its offset (for large offsets the mask and vernier may not overlap at all). We use the term pattern mask because the target is covered by a pattern that does not split into two clear parts as metacontrast masks do. All

**Experiment 1: Variations in mask spatial layout**

In Experiment 1, we investigated how the shape of the masking function is related to the spatial properties of the mask. We changed the mask from a spatially non-overlapping metacontrast mask to a spatially overlapping pattern mask by the addition of a single central element.
mask elements used in this experiment had a luminance of 40 cd/m² (i.e., the same luminance as the target).

Results and discussion

The 1N_1N mask produced the expected B-type masking and showed the strongest masking overall (main effect of mask type: \(F(2,10) = 11.713, p = 0.002\); no significant interaction between mask type and SOA). The 1N mask produced very weak masking that does not seem to vary with SOA. The 3N mask, a superposition of the 1N_1N and the 1N masks, showed masking that was similar to that of the 1N_1N metacontrast mask. That the 3N mask did not show stronger masking than the 1N_1N mask is contrary to some theories of masking that predict that any increase in mask energy should increase the masking strength. Moreover, it also shows that mask elements at the location of the target do not always result in stronger masking, as both the 1N and the 3N mask show weaker or equal masking compared to the 1N_1N mask, even though they all occupy the spatial location of the target. It is not clear whether the masking function for the 3N mask is A-type or B-type.

As shown in Figure 3, a clear difference in performance between metacontrast and pattern masks is obtained for the larger masks 6N_6N and 13N. The 6N_6N metacontrast mask produces an A-type masking function, which is consistent with previous investigations of this kind of mask (e.g., Duangudom et al., 2007). The 13N pattern mask differs from the 6N_6N metacontrast mask only by the addition of the central mask element. This additional masking element dramatically reduces mask strength and the shape of the masking function (main effect of mask: \(F(1,5) = 17.106, p = 0.009\); interaction with SOA: \(F(5,25) = 17.658, p < 0.001\)). Masking by the 13N pattern mask is very similar to that of the 1N mask.

It is noteworthy that the two different metacontrast masks (1N_1N and 6N_6N) produce quite different masking functions (different thresholds at a zero SOA: \(t(5) = 4.819, p = 0.005\), similar thresholds at SOA = 20 ms: \(t(5) = 1.247, p = 0.267\), different thresholds again at SOA = 40: \(t(5) = 5.855, p = 0.002\) despite having the same local contour information around the target vernier, which was often proposed to be the main cause of masking (e.g., Growney, 1977, 1978; Sturr, Frumkes, & Veneruso, 1965; Werner, 1935). Moreover, comparing the A-type masking function in Figure 3 with the B-type masking function in Figure 2 reveals that models that use mask strength to explain the different masking function shapes (e.g., Anbar & Anbar, 1982; Bridgeman, 1971, 1978; Francis, 1997; Weisstein, 1968) cannot match the data. This is because all these models predict that A-type masking should show stronger masking at each SOA than B-type masking functions. However, at the 40 ms SOA, the A-type masking function in Figure 3 generates a lower threshold than the B-type masking function in Figure 2 (\(t(5) = 5.855, p = 0.002\)) thereby providing a violation of this prediction (see also Francis & Herzog, 2004).

Experiment 1 demonstrates that small changes in the mask’s spatial layout can have a strong impact on the strength of masking and on the shape of the masking function. These findings are generally consistent with the conclusions of Duangudom et al. (2007) emphasizing the importance of the spatial layout properties of the mask. We explain these results in terms of perceptual grouping. Masking is strong for the metacontrast masks for short SOAs because the target vernier “completes” the flankers to form a regular array (see Introduction). For the pattern masks, this position is already filled by the central mask element and so the target vernier does not become part of the mask array. Metaphorically speaking, the target vernier is “freed” from the grating (see also Francis & Cho, 2008; Hermens, Herzog, & Francis, 2009; Malania et al., 2007; Sayim, Westheimer, & Herzog, 2008). The LST-energy cannot explain these results because adding more mask elements, the 1N mask, yielded improved performance.

Experiment 2: Variations in luminance

The grouping hypothesis (Duangudom et al., 2007) suggests that mask luminance is not important for mask
strength except for how it changes the tendency for the
target to be grouped with the mask.

To test this hypothesis, Experiment 2 contrasted the
6N_6N and 13N masks from Experiment 1 with a mask in
which we doubled the luminance of the 6N_6N mask
and of the flanking elements of the 13N pattern mask.
The luminance of the central element of the 13N mask
was not doubled. An energy-based view of masking
predicts that such doubling of luminance should lead to
stronger masking for both metacontrast and pattern
masks. The grouping perspective predicts that the addi-
tional luminance will lead to a reduction in masking for
the modified 6N_6N metacontrast mask because the
lower luminance target vernier will be less likely to group
with the higher luminance surrounding mask elements.
For the modified 13N pattern mask, the grouping
perspective predicts strong masking because the target
vernier should integrate with the dim central element and
form a unified group of bright elements. Within this group,
it should be difficult to identify the properties of the target
vernier.

Methods

Two new masks were constructed for Experiment 2. In
the first condition of Experiment 2, we doubled the
luminance of the 6N_6N mask, i.e., the mask elements
had a luminance of 80 cd/m². This mask is labeled as
6dN_6dN, where the ‘d’ indicates the double luminance.
The target vernier luminance was kept at 40 cd/m². In the
second condition, we inserted a 40 cd/m² aligned vernier
element into this mask, thereby obtaining a grating with
a central element that had only half the luminance of the
remaining mask elements (this is referred to as the
6dNN6dN mask). The masks are illustrated in Figure 4.

Results and discussion

Among the pattern masks, strong A-type masking
occurred for the 6dNN6dN mask and virtually no masking
for the 13N mask. These results are consistent within both
the energy and the perceptual grouping hypothesis.

A comparison of the masking effects of the two
metacontrast masks 6N_6N and 6dN_6dN (circles in
Figure 4) shows, consistent with an energy-based view
of masking, that the increased luminance of the 6dN_6dN
mask elements leads to stronger masking (main effect of
mask: $F(1,5) = 7.139, p = 0.044$; interaction with SOA:
$F(5,25) = 15.592, p < 0.001$). This result is contrary to
the grouping hypothesis, which predicts that the differ-
ce in luminance of the target vernier relative to the mask
elements would prevent the target from being grouped with
the mask and thereby would lead to better target detection.

Interestingly, the stronger masking for the double lumi-
nance metacontrast mask is exhibited as B-type masking
(quadratic component of polynomial contrast: $F(1,5) = 5.88, p = 0.06$), with the strongest effect at around a 20-ms
SOA. This B-type masking contrasts with predictions of
many theories of masking where strong masks are more
likely to produce A-type masking (Francis & Herzog,
2004).

Because such strong B-type masking is a surprising
finding and because the statistical test just fell short of
showing a significant quadratic component, the existence
of this type of masking for the 6dN_6dN mask was
confirmed by repeating the experiment with a finer
sampling of 10 ms SOAs. This was done for two observers
who had already participated in the experiment (AD and
MM) and a new observer (JC). Figure 5 shows that the
masking curves in the high luminance condition were
indeed of type B for each observer.

Taken together, the results from Experiment 2 suggest
that masking effects are sensitive to variations in both
luminance and in spatial layout. For the conditions of this
experiment, the luminance effect is modulated by the
spatial layout of the mask. However, the impact of the modulation is not consistent with the perceptual grouping hypothesis.

Experiment 3: Additional variations in luminance and spatial layout

Experiment 2 suggests that neither an energy-based view of masking nor the grouping hypothesis is able to explain the observed data. Certainly, each approach needs to be elaborated to account for the totality of masking effects. Toward that goal, we explored additional variations in luminance and spatial layout that pit the two explanations against each other.

Methods

In Experiment 3, we compared performance on three pattern masks, each consisting of a grating of thirteen straight verniers. In the first mask, every second element in the grating had a luminance of 80 cd/m², whereas the other elements had a luminance of 40 cd/m² (alt-d13N). In this mask, the central element of the grating, overlapping with the vernier, had a luminance of 80 cd/m². The second mask was identical except for the fact that the central element of the grating had a luminance of 40 cd/m² (alt-d6N-1N-alt-d6N). The third mask was a variation of the alt-d13N mask with the luminance of the five central elements set to 40 cd/m² (alt-d4N-5N-alt-d4N). The target always had a luminance of 40 cd/m². Five observers participated. All had participated in Experiments 1 and 2.

Results and discussion

If the LST-energy in the mask is the main determinant for the overall strength of the masking effect, then the alt-d13N mask should have the strongest effect, the alt-d6N-1N-alt-d6N should have a middle effect, and the alt-d4N-5N-alt-d4N mask should have the weakest effect. Moreover, the same order of masking effects is predicted by an explanation based on local lateral inhibition sent to the target by neighboring mask elements. The alt-d13N mask should have the strongest effect because it has the most high intensity elements close to the target. The alt-d6N-1N-alt-d6N metacontrast mask. In this experiment, we repeated the experiment with the d6N_d6N metacontrast mask (see Figure 4) sampled at a finer temporal resolution in steps of 10 ms each. Observers AD and MM participated in the main part of Experiment 2, whereas JC was new to the task. Each data point depicts the mean of two measurements for the respective observer. All three observers show a B-type masking function.

Figure 5. Results of Experiment 2: Double luminance (d6N_d6N) metacontrast mask. In this experiment, we repeated the experiment with the d6N_d6N metacontrast mask (see Figure 4) sampled at a finer temporal resolution in steps of 10 ms each. Observers AD and MM participated in the main part of Experiment 2, whereas JC was new to the task. Each data point depicts the mean of two measurements for the respective observer. All three observers show a B-type masking function.

Figure 6. Results of Experiment 3: Vernier offset discrimination thresholds for three different pattern masks. Diamonds represent the mean performance for the pattern mask with a central element of 40 cd/m². Circles depict mean performance for the pattern mask where every second element had a luminance of 80 cd/m². Squares represent mean performance for the pattern mask with five central elements iso-luminant to the target. The solid horizontal line shows performance in the vernier only condition. Bold lines in the stimulus illustrations indicate a luminance of 80 cd/m² and gray lines a luminance of 40 cd/m². Strongest masking is found when the vernier adds to the grating, thereby forming an alternating pattern of lower and higher luminance elements, suggesting that grouping is essential in explaining the strength of a mask.
1N-alt-d6N should have a slightly weaker effect because the middle element is not high intensity. The alt-d4N-5N-alt-d4N mask should have the weakest effect because the high intensity elements are all far from the target vernier. Figure 6 demonstrates that this prediction is not correct. Instead, the mask with the middle amount of energy (alt-d6N-1N-alt-d6N) has the strongest masking effect (main effect of mask type: $F(2,8) = 18.794, p = 0.001$; interaction with SOA: $F(10,40) = 4.946, p < 0.001$) while the masks with the most and least LST-energy have similar masking effects.

In contrast, the grouping hypothesis predicts the observed pattern of results. The alt-d6N-1N-alt-d6N mask should produce strong masking at the shortest SOAs because when the target integrates with the central element of the mask, the resulting pattern becomes a regular alternating sequence of high and normal intensity elements. This pattern will make the target properties difficult to judge. In contrast, the alt-d13N mask should produce weaker masking despite its high energy. When the target and mask integrate at the shortest SOAs, the center has triple the intensity of a normal mask element. As a result, the vernier does not group with the rest of the mask and the offset of the vernier target can be observed more readily. Likewise, the alt-d4N-5N-alt-d4N mask should not produce a strong grouping effect because the integrated target and center mask element will stand out from the neighbors which have a lower luminance. The grouping hypothesis does not make a prediction whether the alt-d13N or the alt-d4N-5N-alt-d4N mask should produce stronger masking.

**General discussion**

The experiments reported here investigated how changes in mask luminance and global spatial layout affect the shape of the masking curve and the strength of masking.

**Mask energy and other low-level aspects**

Experiment 1 shows that adding further mask elements can lead to a decrease in the strength of masking. Hence, the LST-energy cannot explain mask strength, in agreement with earlier observations for simultaneous masking (Malania et al., 2007), pattern masking (Herzog & Koch, 2001), and metacons-trast masking (Duangudom et al., 2007). The findings of Experiment 2, however, support the idea that mask energy contributes to masking strength, as doubling the luminance of the metacons-trast mask (d6N_d6N) results in stronger masking. Experiment 3 again challenges energy theories because the highest energy mask (alt-d13N) did not yield the strongest masking. It therefore seems that the LST-energy of a mask does not play an important role in determining the masking strength and the shape of the masking function. However, luminance and LT-energy are of importance even though their effects are not as straightforward as often believed (see Experiment 2).

For the very same reasons, Experiments 1 and 3 also challenge an explanation in terms of lateral inhibition between the mask elements and the target (Grown-ney, 1977, 1978; Sturr et al., 1965). In addition, basic contour interactions between the outer contour of the target and the inner contours of the mask cannot explain the findings either (Werner, 1935). The 1N_1N mask and the 6N_6N mask have the same inner contours; however, masking strength and masking function shape are very different.

**Grouping**

The results of Experiment 1 are in agreement with the grouping hypothesis. For example, the 6N_6N metacontrast mask exerts much more masking than the 13N mask. We suggest that the vernier target spatially fits well within the gap of the 6N_6N mask and, as a consequence, is strongly grouped with the mask elements for short SOAs (Figure 3; see also Duangudom et al., 2007). For longer SOAs, this spatial grouping is broken by temporal cues. Adding the single vernier mask 1N, which exerts almost no masking when presented alone, to the 6N_6N mask improves performance because the resulting 13N mask is a regular grating, and thus the vernier target is not integrated into the mask. It stands out from the mask elements as being brighter because of the luminance increment in the center, resulting from the combination of the vernier plus the center mask element.

In general, it seems that “completing” a metacons-trast mask to form a regular grating by adding the single vernier mask strongly improves performance. On the other hand, adding an entire grating to a mask does not change performance too much even though luminance is dramatically increased (compare the 6N_6N and 6dNN6dN masks in Experiment 2). These findings are summarized in Figures 7 and 8, with old data and new data, highlighting the importance of regularity for masking strength.

Accordingly, in Experiment 2, masking strength increases when the luminance of the flanker elements of the 13N pattern mask is increased to 80 cd/m², resulting in the 6dN6dN mask. This increase in masking strength is predicted by the grouping hypothesis because the 40 cd/m² target and 40 cd/m² central mask element add up to an 80 cd/m² central element and consequently, all elements are grouped because of identical luminance. Also Experiment 3 is largely in agreement with the grouping hypothesis.

However, the grouping hypothesis proposes diminished masking when the luminance of the 6N_6N metacons-trast
mask is increased to 80 cd/m² because, after this increase, the mask elements and target do no longer have the same luminance. However, the opposite result was found. Masking strongly increased and was, even more surprising, of type B.

This appearance of B-type masking for the double luminance metacontrast mask is the most puzzling finding of all. The B-type masking of the d6N_d6N mask was much stronger than the corresponding A-type masking of the lower luminance 6N_6N metacontrast mask, at least for SOAs up to 80 ms. To our knowledge, this is the first instance in which a large part of a B-type masking curve shows stronger masking than the corresponding A-type masking curve (i.e., with the same target and task). This result strongly violates predictions of classical theories of masking that B-type masking should always be weaker than A-type masking (Francis & Herzog, 2004).

Thus, we are left with the conclusion that there is evidence that both mask LT-energy/luminance and grouping processes between the target and the mask play an important role in masking (whereas LST-energy cannot predict performance). It still might be possible to explain the effects of luminance within the grouping hypothesis. The only difficult case for the grouping hypothesis is the puzzling B-type masking of the double luminance metacontrast mask in Experiment 2. It is generally accepted that the higher the luminance of a visual stimulus, the larger the related neural responses. We suggest that neural activity is also enhanced for stimulus elements that are inhomogeneous such as edges of regular gratings. When, for example, the visual system is presented with the 6N_6N mask, the inner structure of the two flanking 6N structures is suppressed, whereas the activity related to the outer and inner edges is enhanced. The enhanced activity of the inner edges suppresses the vernier target. When the single element mask is added to the 6N_6N mask, a complete grating mask is created (13N), and therefore the former inner elements are mutually suppressed by their neighbors of which one is the central element. As a consequence, because there is no remaining activity related to the inner elements, the vernier is less strongly suppressed. If the luminance of the 6N_6N mask is increased to 80 cd/m² because, after this increase, the mask elements and target do no longer have the same luminance. However, the opposite result was found. Masking strongly increased and was, even more surprising, of type B.

Figure 7. Adding a single aligned vernier to the center of a mask. In each of the subplots, performance for three masks is shown. The lower mask in the subplots, indicated by the green squares, are the “sum” of the upper masks (red circles) and the single vernier mask. Adding this single vernier strongly improves performance in all conditions (in the right upper panel, performance is close to the unmasked condition for all three masks). Most of the data are replotted from Experiments 1 and 2. Performance in two new conditions is shown in the right panels (in the upper right panel, the new mask consists of 12 flankers with 40 cd/m², green squares, whereas the center element is displayed with 80 cd/m²; in the lower right panel, all elements of the new mask elements have a luminance of 80 cd/m², green squares).
mask is doubled (6dN_6dN mask), activity related to the
inner edges increases because of the luminance increase
and the irregularity. These considerations are in accord-
ance with recent models of visual masking (e.g.,
Francis, 2009; Hermens, Luksys, Gerstner, Herzog, &
Ernst, 2008; Herzog et al., 2003); however, they remain
speculation at the moment because the models are not
designed to consider these conditions. Moreover, it remains
unknown why the enhanced masking with the double
luminance metacontrast mask (d6N_d6N) is of B-type.

For the moment, it also remains unknown how other
models of masking deal with the current results. For
example, adding elements to the mask changes not only its
energy and spatial layout but also its spatial frequency
spectrum, which is of major importance to the dual
channel model of masking (Breitmeyer & Ganz, 1976).
Only computational simulations can determine the exact
masking function for this model, but such simulations do
not currently exist. An analogous argument holds for the
retouch theory (Bachmann, 1994). For object substitution
masking (Di Lollo, Enns, & Rensink, 2000), it is not clear
how exactly the mask and target interact. It is, however,
very unlikely that any of these models can explain the
B-type masking of the d6N_d6N mask because most
models of visual masking predict that an increase in the
mask’s luminance should change masking into A-type
(Francis & Herzog, 2004). Finally, we like to mention that
the grouping account described above operates on a
description level of perceptual organization. This con-
trasts, in particular, with the dual channel model and the
retouch theory, which deal with neural mechanisms. This
means that these models and our grouping account are
independent, leaving open the possibility that either of
them may be correct or incorrect. Our results are generally
in accordance with some previous findings that emphasize
the importance of grouping factors for visual masking
(Purcell & Stewart, 1988; Ramachandran & Cobb, 1995;
Williams & Weisstein, 1984). However, those previous
studies were unable to identify how grouping effects
contrasted with other masking influences.

Applications of masking

One important practical implication of the current
findings is that choosing an appropriate mask should not
be taken lightly. In many applications of visual backward
masking, it is important that the mask produces an A-type

Figure 8. Adding an entire grating of aligned verniers to a mask. In each subplot, performance is shown for two masks of which the second
one is created from the first one by adding a grating of which all elements have a luminance of 40 cd/m², i.e., adding the 13N mask. Performance changes only slightly by adding the 13N grating even though mask energy may be doubled.
masking function so that increases in the SOA leads to weaker masking. Our results show that higher luminance pattern masks do not always lead to stronger masking and that there is no reliable way to tell which target and mask combination is going to yield A-type masking. Therefore, before using masking as a tool in which the SOA is varied, it is crucial to determine the shape of the masking curve experimentally (e.g., Francis & Cho, 2008; Hermens et al., 2009).

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