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Effects of Temporal Integration on the Shape of Visual Backward Masking Functions

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Many studies of cognition and perception use a visual mask to explore the dynamics of information processing of a target. Especially important in these applications is the time between the target and mask stimuli. A plot of some measure of target visibility against stimulus onset asynchrony is called a *masking function*, which can sometimes be monotonic increasing but other times is U-shaped. Theories of backward masking have long hypothesized that temporal integration of the target and mask influences properties of masking but have not connected the influence of integration with the shape of the masking function. With two experiments that vary the spatial properties of the target and mask, the authors provide evidence that temporal integration of the stimuli plays a critical role in determining the shape of the masking function. The resulting data both challenge current theories of backward masking and indicate what changes to the theories are needed to account for the new data. The authors further discuss the implication of the findings for uses of backward masking to explore other aspects of cognition.

Keywords: backward masking, metacontrast, visual search, integration masking, interruption masking

A brief visual target stimulus can be difficult to see if it is followed by a visual mask stimulus. Such masking effects have a long history in psychology and have remained an active area of investigation for over 100 years (see reviews by Bachmann, 1994; Breitmeyer, 1984; Breitmeyer & Ögmen, 2006; Kahnemann, 1968; Kolers, 1983). In this article, we focus on variations in the strength of masking as a function of the temporal separation between the stimuli. When judgments about the target are plotted as a function of the stimulus onset asynchrony (SOA) between the target and mask, the resulting curve is called a *masking function*.

Masking functions are used in a wide variety of studies. Figure 1A shows a masking function from Bacon-Macé, Macé, Fabre-Thorpe, and Thorpe (2005), who explored the time needed to perform natural scene categorization by presenting a dynamic mask after an image. Here the strongest masking occurs at the shortest SOA, and increases in SOA lead to better detection of the target attributes. Such a monotonically increasing masking function is referred to as *Type A masking*. Type A masking can be compared with *Type B masking*, where the strongest masking occurs for an intermediate SOA. Figure 1B shows a masking function from Rassovsky, Green, Nuechterlein, Breitmeyer, and Mintz (2005), who compared masking effects for schizophrenic patients and healthy comparison participants. Here target detection is worst when the mask follows the target by 40–65 ms. Explaining the difference between Type A and Type B masking functions has been one of the major issues in studies of masking (e.g., Alpern, 1953; Breitmeyer & Ögmen, 2000, 2006; Eriksen, Becker, & Hoffman, 1970; Francis, 2000).

The properties of backward masking and the shapes of the masking functions are important because masking is often used to investigate the temporal properties of cognitive processing. Stimuli are often masked to investigate properties of subliminal or nonconscious processing (Ansorge, 2003; Klotz & Neumann, 1999; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003). High-contrast stimuli are sometimes masked to degrade a stimulus so that other effects can be measured away from ceiling effects. A classic example of this use is the word superiority effect (Jordan & de Bruijn, 1993; Reicher, 1969; Wheeler, 1970). Masking is also used as a means of limiting the processing time of stimuli in studies of topics such as IQ and inspection time (Burns, Nettelbeck, & White, 1998), natural scene categorization (Bacon-Macé et al., 2005), picture memory (Loftus, 1985), and face adaptation (Carbon & Leder, 2005). Many experimental effects such as the attentional blink (Dell'Acqua, Pascali, Jolicoeur, & Sessa, 2003; Giesbrecht & Di Lollo, 1998) and the word superiority effect (Johnston, 1981) appear to critically depend on the presence of masking stimuli.

These uses of masking have been criticized as introducing confounds to experiments (Eriksen, 1980; Marchetti & Mewhort, 1986; Smithson & Mollon, 2006). The most serious concern is that it is not known exactly what the mask does to make the target difficult to process. Such a lack of understanding means that it is possible that masks influence different targets in different ways. More generally, until one understands the effect of the mask on the target, it is difficult to discuss any other effects that depend on the mask's presence.

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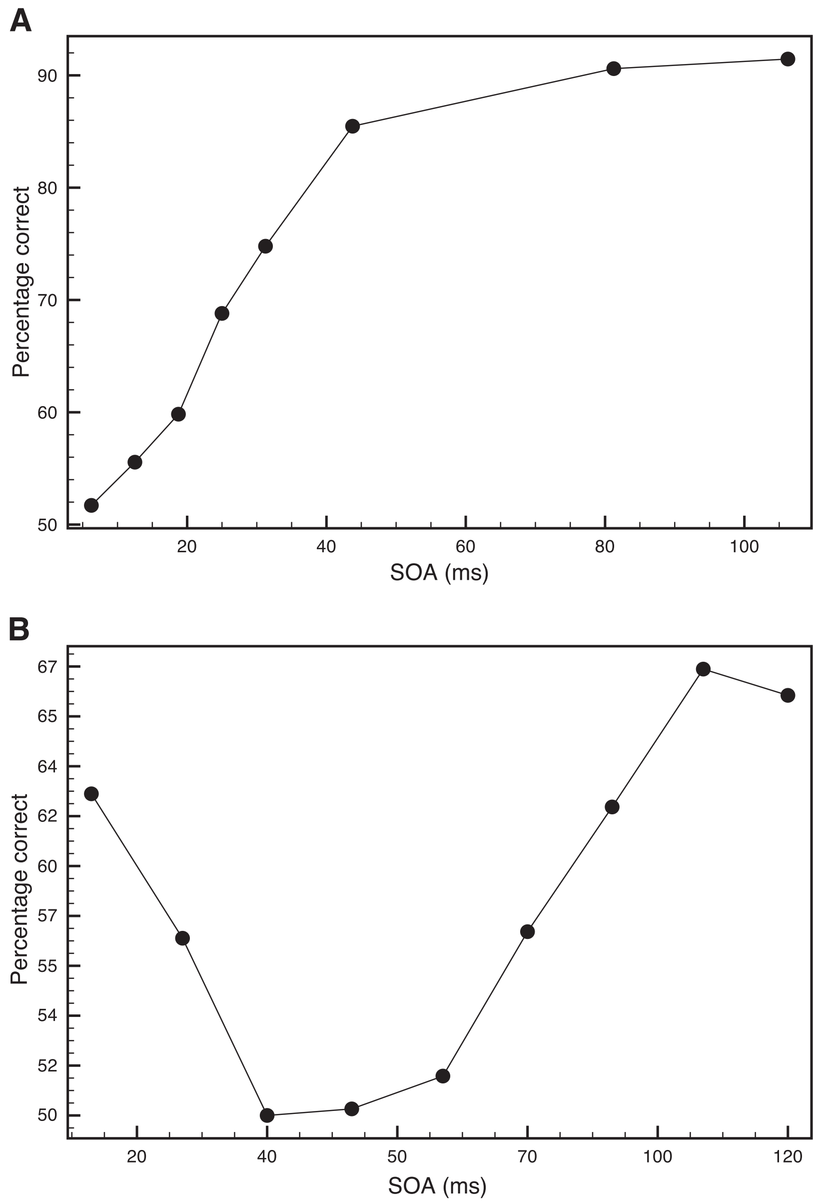

Figure 1. Examples of two types of masking functions. Each graph plots the percentage of correct detections of some target property as a function of the stimulus onset asynchrony (SOA) between the target and mask stimuli. A: Type A masking function where the mask's effect on the target is maximal at the shortest SOA and grows weaker with larger SOA values. Adapted from "The Time Course of Visual Processing: Backward Masking and Natural Scene Categorisation" by N. Bacon-Macé, M. J. M. Macé, M. Fabre-Thorpe, and S. J. Thorpe, 2005, *Vision Research*, *45*, p. 1462. Copyright 2005 by Elsevier. Adapted with permission. B: Type B masking function where the mask's effect on the target is maximal at a positive SOA and is weaker for shorter or longer SOA values. Adapted from "Modulation of Attention During Visual Masking in Schizophrenia" by Y. Rassovsky, M. F. Green, K. H. Nuechterlein, B. Breitmeyer, and J. Mintz, 2005, *American Journal of Psychiatry*, *162*, p. 1534. Copyright 2005 by the American Psychiatric Association. Adapted with permission.

Many researchers distinguish between integration and interruption masking mechanisms (Enns, 2004; Eriksen, 1966; Kolers, 1983; Michaels & Turvey, 1979; Scheerer, 1973; Spencer & Shuntich, 1970). Integration masking is hypothesized to occur when the target and mask stimuli merge together over time. This temporal integration may lead to luminance summation and a reduction in target contrast (Eriksen, 1966; Eriksen & Hoffman, 1963) or to camouflage effects where the target properties are difficult to identify (Schultz & Eriksen, 1977; Uttal, 1970). Interruption masking is said to occur when the processing of information about the target takes time and the mask arrival curtails the processing of the target. This curtailment could be because the mask erases the target from iconic memory (Sperling, 1963) or because the mask halts processing of still present target information (Turvey, 1973). The object substitution idea proposed by Enns and Di Lollo (1997) is a variation of interruption theories.

Although the concepts of integration and interruption masking have been around for decades, it is not entirely clear how these mechanisms relate to masking function shapes. Eriksen and Hoffman (1963) proposed that integration masking effects should produce Type A masking, because with increasing SOA, the target and mask should be less likely to temporally integrate and the target should be more visible. However, Navon and Purcell (1981) argued that temporal integration between the target and mask should hardly be considered a mechanism for masking, because if the target and mask do not temporally integrate, then either the target, the mask, or both would not be visible at all. Thus, they argued that temporal integration actually protects the target from masking effects produced by a trailing stimulus. Reeves (1982) followed up on this line of thought and found empirical evidence that the downward slope of a Type B masking function was due to a reduction in the occurrence of temporal integration between the target and mask. Likewise, Stewart and Purcell (1970) noted that a Type B masking function requires that the target be clearly visible when presented simultaneously with the mask, whereas Eriksen (1980) noted that Type A masking necessarily requires that the target be hidden when presented simultaneously with the mask.

It is equally unclear whether interruption masking should produce Type A or Type B masking functions. Interruption masking is often described as a mechanism that is capable of explaining Type B masking functions (Enns & Di Lollo, 1997, 2000), but it is also described as a mechanism for controlling the duration of target information processing (Bacon-Macé et al., 2005; Eriksen, 1980). Such control would only be reasonable for Type A masking, because otherwise increasing the SOA would sometimes increase and sometimes decrease the processing duration of the target.

Further confusing the issue are experimental findings regarding the appearance of Type A and Type B masking functions. Several studies have found that different kinds of masks tend to produce Type A or Type B masking functions. A mask of a bright flash of light (Kolers, 1962; Sperling, 1965) or a dense set of random dots (Kinsbourne & Warrington, 1962) tends to produce Type A masking functions. However, there are exceptions where such masks produce Type B masking (Delord, 1998; Stewart & Purcell, 1974). Pattern masks, where the mask is made of stimulus parts with contours that overlap the target (Turvey, 1973), and metacontrast masks, where the mask contours do not overlap the target contours (Alpern, 1953), tend to produce Type B masking functions. However, when a pattern or metacontrast mask is more intense or has a longer duration than the target, it can produce a Type A masking function (Breitmeyer, 1978; Kolers, 1962; Weisstein, 1972).

Other theories of masking cannot be characterized as integration or interruption but rather propose various types of neural inhibition. Breitmeyer and Ganz (1976) argued that Type B masking occurred when fast-acting transient signals from the mask inhibited slower acting sustained signals from the target. The strongest masking occurs at an intermediate SOA because transient signals appear sooner than do the sustained signals. To provide maximum inhibitory overlap of the signals, the mask must be delayed relative to the target. In this theory, Type A masking occurs when there is also strong inhibition from the mask-sustained signals to the target-sustained signals. Such masking has its strongest effect at a zero SOA because common onset produces the most overlap of the mask's sustained inhibition with the target's sustained responses. In this theory, the mask's sustained inhibition tends to be weak, so the mask intensity or duration must be strong, relative to the target stimulus, to have much of an effect. Recent quantitative simulations of this type of model (e.g., Ögmen, Breitmeyer, & Melvin, 2003) have had good success matching and predicting experimental data.

Several other quantitative models have also hypothesized some type of inhibition to explain masking effects (Anbar & Anbar, 1982; Bridgeman, 1971, 1978; Francis, 1997; Weisstein, 1972). Francis and Herzog (2004) analyzed these quantitative models and showed that they could produce both Type A and Type B masking functions. For all of these models, Francis (2000) showed that they use a general approach called mask-blocking, where signals from the target block the inhibitory effects of the mask. Type B masking occurs because the strong target signals block mask inhibition at the shortest SOAs. For longer SOAs, the target signals fade over time and the mask inhibition is not blocked. Part of this approach requires that Type B masking functions appear when the mask inhibition is relatively weak, whereas Type A masking functions appear when the mask inhibition is so strong that it cannot be effectively blocked. In their analysis, Francis and Herzog (2004) showed that all of these models predict that the shape of the masking function is related to the strength of masking. For a fixed target and task, the strength of masking for a mask that produces Type A masking at each SOA should be equal to or stronger than the strength of masking for a mask that produces Type B masking. This pattern is also a prediction of the Breitmeyer and Ganz (1976) theory, because Type A masking involves sustained inhibition in addition to the transient inhibition that generates Type B masking. In the experimental part of their study, Francis and Herzog (2004) showed that this prediction did not hold by varying the spatial properties of the mask.

Francis and Cho (2005) found a similar violation of the model predictions with stimuli different from those used by Francis and Herzog (2004). In addition, Francis and Cho hypothesized that the shape of the masking function in their study was related to temporal integration effects at the shortest SOAs. Their argument echoed the ideas of Bachmann and Allik (1976), who suggested that integration effects played a role in both Type A and Type B masking functions. Namely, when temporal integration occurs at the shortest SOAs, the resulting percept will sometimes make the target easy to identify and sometimes make the target difficult to identify, with the differences depending on the spatial properties of the target and mask stimuli. This view combines traditional interpretations of temporal integration masking effects (Eriksen, 1966) and the idea that temporal integration protects the target (Navon & Purcell, 1981). The view also provides a candidate explanation for why the quantitative models studied by Francis and Herzog (2004) fail to match the data. All of those models fail to include information about the spatial properties of the target and mask stimuli. If Bachmann and Allik (1976) and Francis and Cho (2005) are correct, the spatial shape of the target and mask stimuli are critical to determining whether a masking function is Type A or Type B.

To explore this issue, we introduce a fundamentally new approach to studying the properties and mechanisms of backward masking. Most studies of masking use a single target (or a small set of very similar targets) and explore how a single mask influences visibility of the target. Indeed, researchers who use masking to explore other aspects of cognition are often advised to design a mask that is crafted for the specific purpose of their experiment (Eriksen, 1980; Haber, 1970; Lleras & Enns, 2004). We do not disagree with these calls for careful mask design, but we also argue that the properties of a single mask are unlikely to allow researchers to understand the mechanisms of masking. Instead, we believe that masking mechanisms will be revealed by observing effects for many different target and mask stimuli. Rather than looking at the detailed effects of a given mask on a given target, we are interested in the statistical pattern of masking effects across the different target and mask stimuli. Previous studies that compared masking for different kinds of masks (Delord, 1988; Enns, 2004) have not varied properties of the target or looked for relationships between stimuli and the shape of the masking function.

Experiment 1: Backward Masking

Method

We measured the masking function for every combination of four targets and five masks. Figure 2 schematizes a trial for one combination of target and mask stimuli. The target frame consisted of four elements (three standard elements and one slightly different, odd element) centered on the corners of a virtual square measuring 12.06° on each side. The observer's task was to report the location of the odd item that was placed randomly among the standard elements. The target frame was shown for one refresh of the 85-Hz monitor (approximately 12 ms).

The target frame elements are shown in the top row of Figure 3. We refer to the first pair as *dots*. The standard elements are made of four square dots (0.17° visual angle) arranged in a virtual square (0.92° visual angle). The odd element is similar but has a smaller width (0.57° visual angle). The second target frame elements are referred to as *lines*. The standard elements were outline squares (0.92° visual angle), whereas the odd element was the same shape with a total of 35% of each side

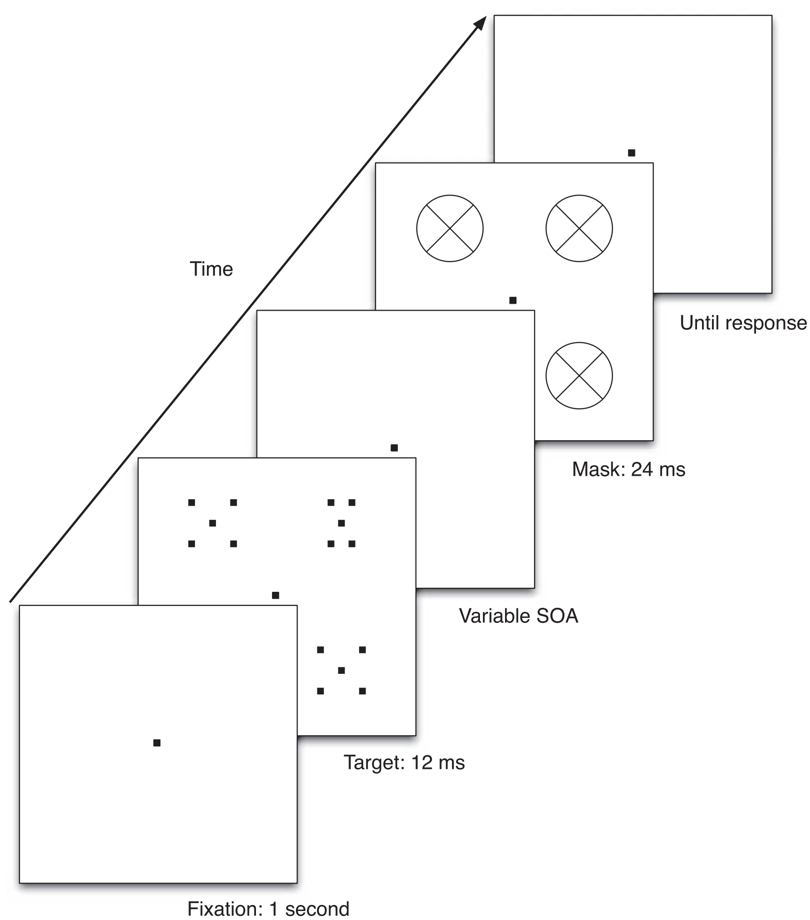

Figure 2. A schematic trial from Experiment 1. All stimuli are shown in reverse contrast. After a fixation frame, a target frame was shown that consisted of three standard elements and one odd element. The observer's task was to report the location of the odd element. After a variable stimulus onset asynchrony (SOA), a mask frame was shown that included four masks, one at each target element location.

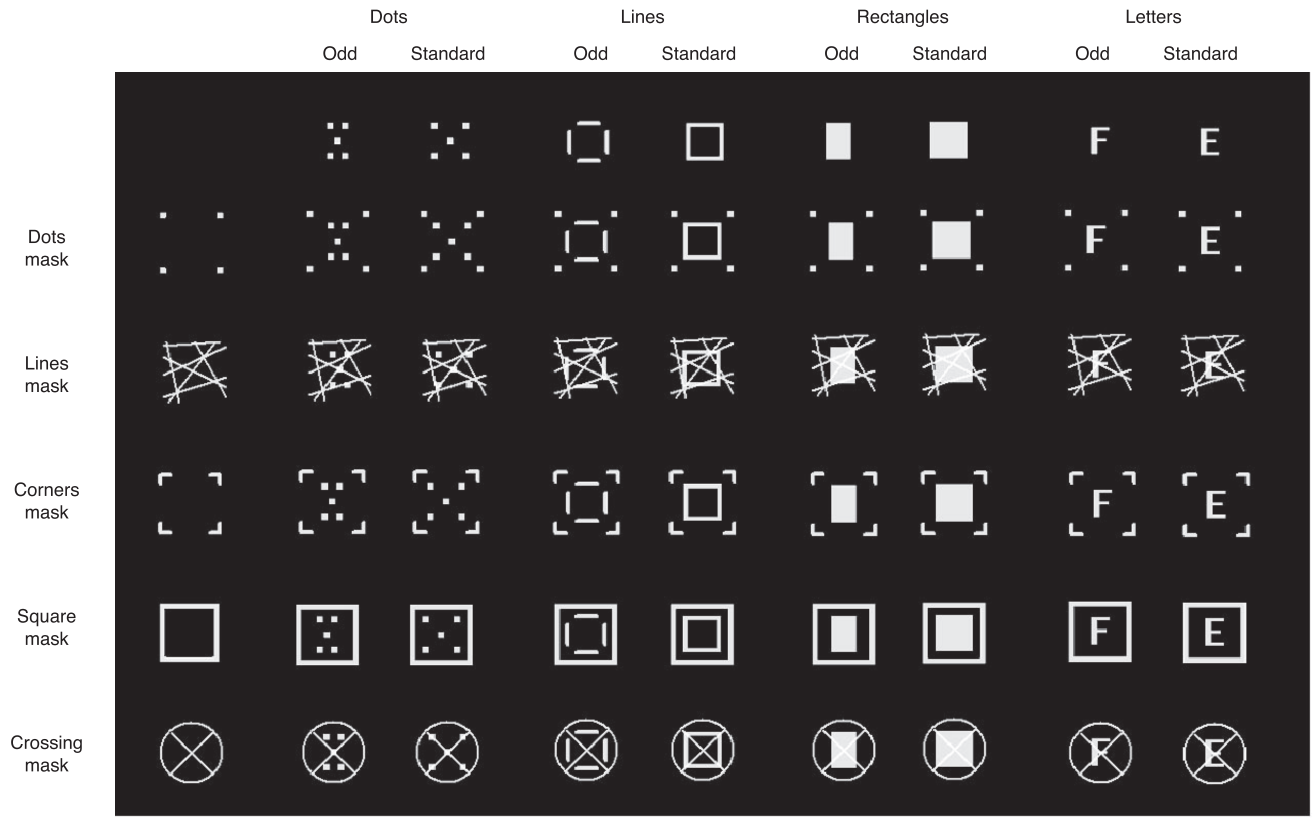

Figure 3. The types of target and mask stimuli used in the experiments. The first row shows the four pairs of standard and odd elements that were used to create the different target frames. The first column shows the five types of mask elements. Each cell in the table shows the stimuli presented at zero stimulus onset asynchrony when the target elements and the mask elements are presented simultaneously.

removed from the corners. The third target elements are referred to as *rectangles*. These were filled rectangles the same size as the dots stimuli. The last target frame elements are referred to as *letters*. The standard element was a block capital letter E, whereas the odd element was a block capital letter *F* (0.4° and 0.63° visual angles wide and high, respectively). The targets elements were all white (180 cd/m^2) on a black (0.6 cd/m^2) background, except for when the target and mask frames were presented simultaneously, as discussed below. All luminance measurements were recorded with a stimulus that filled the aperture of the light meter. The experiment room was dark except for light from the computer monitor.

The target frame was presented with or followed by a mask frame after an SOA of 0, 24, 47, 71, or 94 ms (0, 2, 4, 6, or 8 refresh frames). The mask frame was always shown for 24 ms (2 refresh frames). The four mask elements were centered on the corners of the same virtual square as the target frame elements and either surrounded or overlapped the target frame elements. The different mask elements are shown in the first column of Figure 3. From top to bottom, they are referred to as *dots mask*, *lines mask*, *corners mask*, *square mask*, and *crossing mask*. Each of these mask elements had a width and height of 1.43° visual angle. The lines for the lines mask and the crossing mask had a thickness of 0.08° visual angle (half the thickness of the lines for the corners and square masks).

The cells within Figure 3 display the image shown for a zero SOA. Where the mask elements overlapped the target frame elements, the intensity of the image was set to 205 cd/m^2. This intensity was chosen so that the percept looked similar to that when the target frame and mask frame temporally integrated at short positive SOAs.

Each trial was started with a keypress and presentation of a central fixation point for 1 s. After viewing the stimuli, the observer used the keyboard to indicate the location of the odd element in the target frame. Feedback was given on whether the observer's report was correct for each trial. Only one target frame type and mask frame type combination was used within an experimental session. For each target frame and mask frame combination, the observer saw 100 trials for each SOA. With 20 target frame and mask frame combinations and five SOAs, each observer saw 10,000 trials in the entire experiment. All trials within a session were presented in random order.

There were 3 observers, 2 who were naive as to the purpose of the study and Yang Seok Cho. All observers had extensive practice with the experimental task.

Results

Figures 4, 5, 6, and 7 plot the percentage of correct identification of the target odd element location as a function of SOA for each of

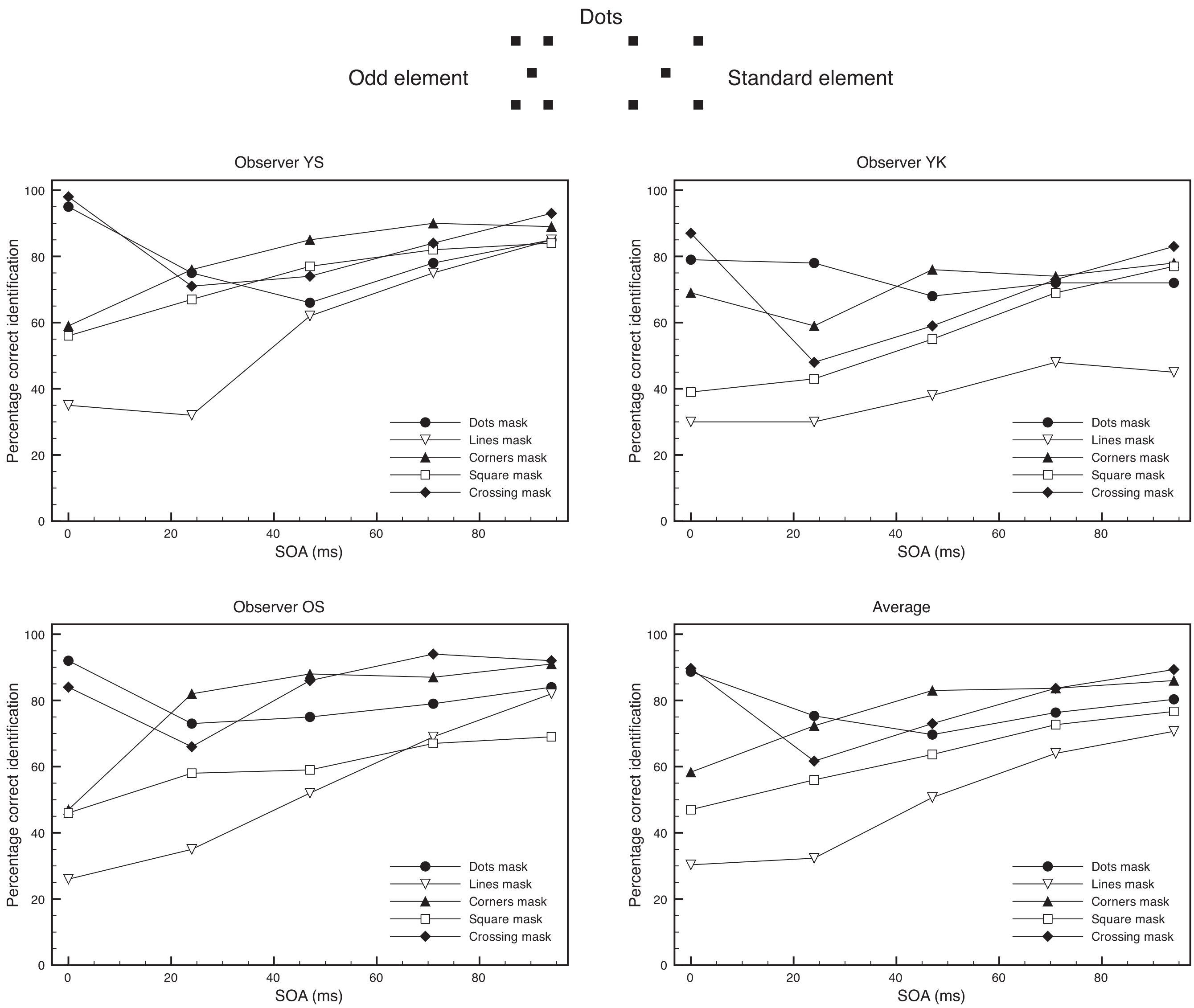

Figure 4. Masking functions from Experiment 1 for the dots. Results for each observer (and an average across observers) are shown in separate graphs. Within each graph, the different curves are for different masks. SOA = stimulus onset asynchrony.

the different target frame types (shown at the top of each figure). Each observer's data are shown in a separate plot. Separate curves in each plot correspond to the different mask types. With 100 trials for each data point, the maximum standard error would be 5 percentage points (when the observer's identification rate is 50% correct). When the observer's identification rate is 90%, the standard error would be 3 percentage points.

There are quantitative differences between the observers, but the observers tend to show the same qualitative patterns. The Pearson correlation coefficient for pairs of observers across all 100 target, mask, and SOA conditions was 0.856 for Observers YS and YK, 0.893 for Observers YS and OS, and 0.839 for Observers YK and OS. Figures 4–7 include a plot of the average percentage across the 3 observers. For most of the discussion below, we refer to the average percentages, but we also indicate when there are substantive differences among the observers.

Figure 4 shows the masking functions for the dots target frame. The dots mask and crossing mask produced Type B masking, whereas the other masks generally produced Type A masking. The lines mask produced the strongest masking, whereas the crossing mask showed the weakest masking, averaged across all SOAs.

Figure 5 shows the masking functions for the lines target frame. The lines mask and crossing mask produced strong Type A masking. Masking is quite weak for most of the other mask types. However, Observer YK shows Type B masking for the corners mask.

Figure 6 shows the masking functions for the rectangles target frame. The lines mask produced strong Type A masking. The corners mask, square mask, and crossing mask all generally show Type B masking functions. The dots mask generated little masking for Observers YK and OS, but it produced modest Type B masking for Observer YS.

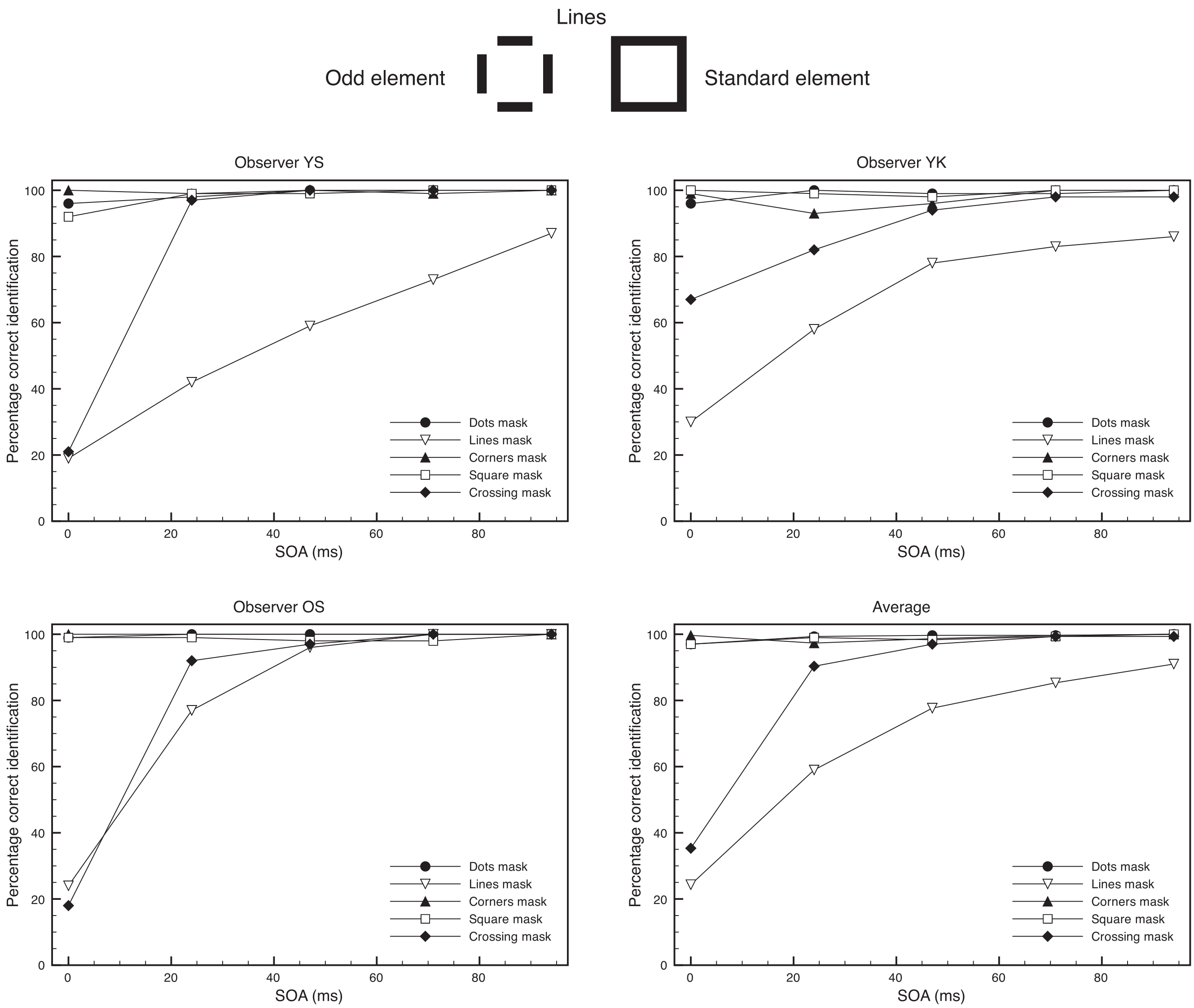

Figure 5. Masking functions from Experiment 1 for the lines. Results for each observer (and an average across observers) are shown in separate graphs. Within each graph, the different curves are for different masks. SOA = stimulus onset asynchrony.

Figure 7 shows the masking functions for the letters target frame. The lines mask and crossing mask produced strong Type A masking, whereas the corners mask produced weaker Type A masking. The square mask produced a Type B masking function, and the dots mask produced quite weak masking that might be Type B.

Discussion

One conclusion from the study is that the shape of the masking function is not related to the spatial shape of the target elements only. A given target produced Type A or Type B masking, depending on the properties of the mask. To our knowledge, the shape of the masking function has never been hypothesized to be due only to the spatial shape of the target elements, so this conclusion is not surprising. The data do, however, challenge many theories about the mechanisms of backward masking.

There is a general view in the field that the shape of the masking function is related to the spatial shape of the mask (Enns & Di Lollo, 2000). Our data indicate that this view is not true. The dots mask produced a Type A masking function in Figure 5 and Type B masking functions in Figures 4, 6, and 7. The corners mask likewise produced Type A masking functions in Figures 4 and 7 but produced Type B masking functions in Figures 5 and 6. The square mask produced Type A masking functions in Figures 4 and 5 but produced Type B masking functions in Figures 6 and 7. The crossing mask produced Type A masking functions in Figures 5 and 7 but produced Type B masking functions in Figures 4 and 6. The only exception to this general property is the lines mask,

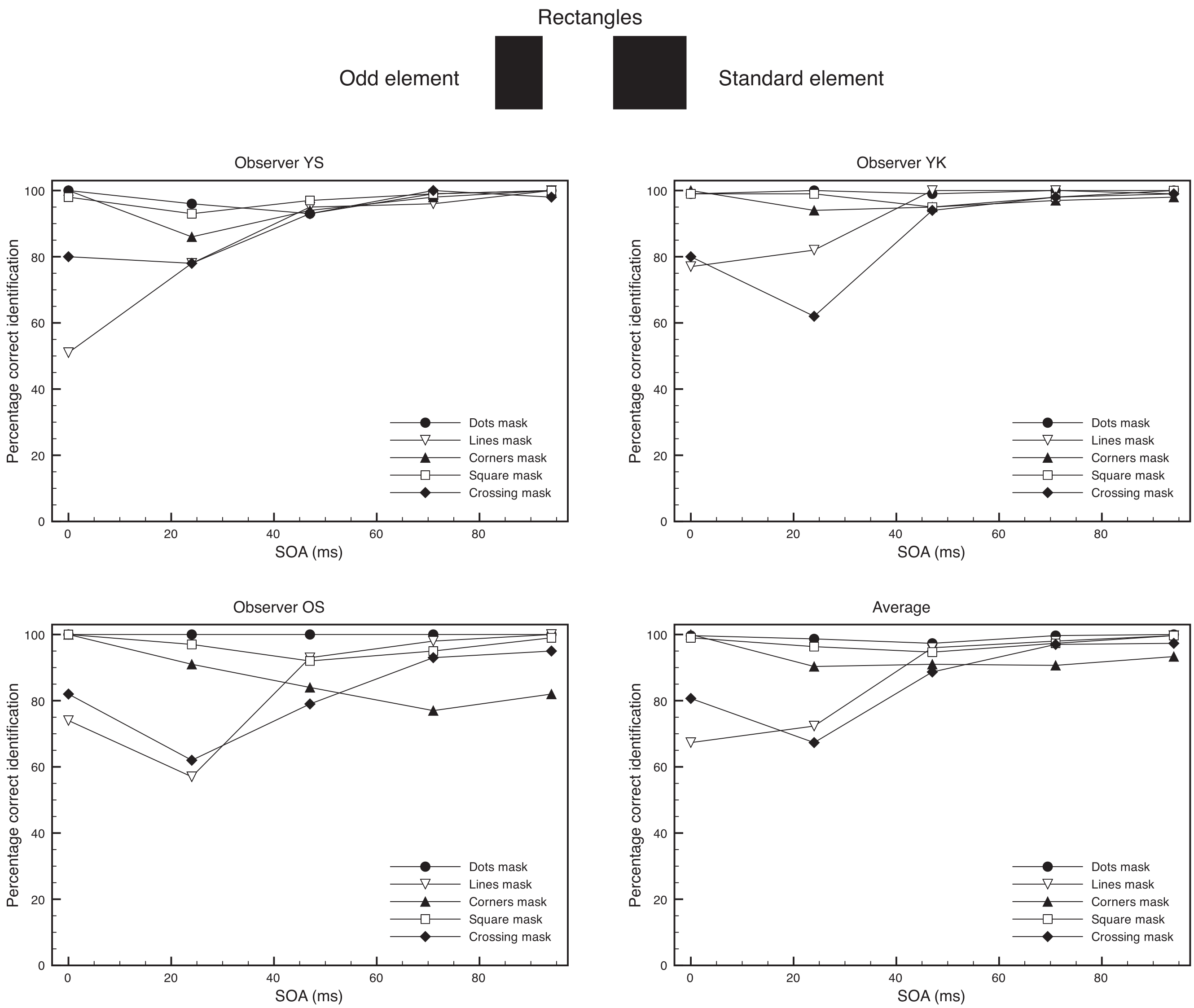

Figure 6. Masking functions from Experiment 1 for the rectangles. Results for each observer (and an average across observers) are shown in separate graphs. Within each graph, the different curves are for different masks. SOA = stimulus onset asynchrony.

which always produced Type A masking functions in our study. Given the pattern in our data, we expect that this mask will also produce Type B masking functions for still different target elements.

Our data also reject an alternative view (Hellige, Walsh, Lawrence, & Prasse, 1979; Oyama, Watanabe, & Funakawa, 1983) that the overall strength of masking is related to the similarity between the target and the mask. For example, the dots mask does not have a particularly strong effect on the dots target and the squares mask is not the strongest masker for the rectangles or the lines target.

The data also provide additional evidence against the models analyzed by Francis and Herzog (2004). They showed that in a variety of quantitative models, the shape of the masking function was intimately related to the overall strength of masking. The models predict that for a fixed target, a Type B masking function should be above a Type A masking function at every SOA. The current data often violate this prediction. For example, with the dots target frame (Figure 4), the corners mask produces a Type A masking function that intersects the Type B masking functions generated by the dots and crossings masks. The experimental results provide mounting evidence against the explanations of masking function shape proposed by these models (Duangudom, Francis, & Herzog, 2007; Francis & Cho, 2005, 2007; Francis & Herzog, 2004).

One remaining possible explanation is the approach espoused by Bachmann and Allik (1976) and Francis and Cho (2005). They argued that the critical determinant of whether a masking function was Type A or Type B was the visual appearance of the target and mask stimuli when they integrated together at the shortest SOAs.

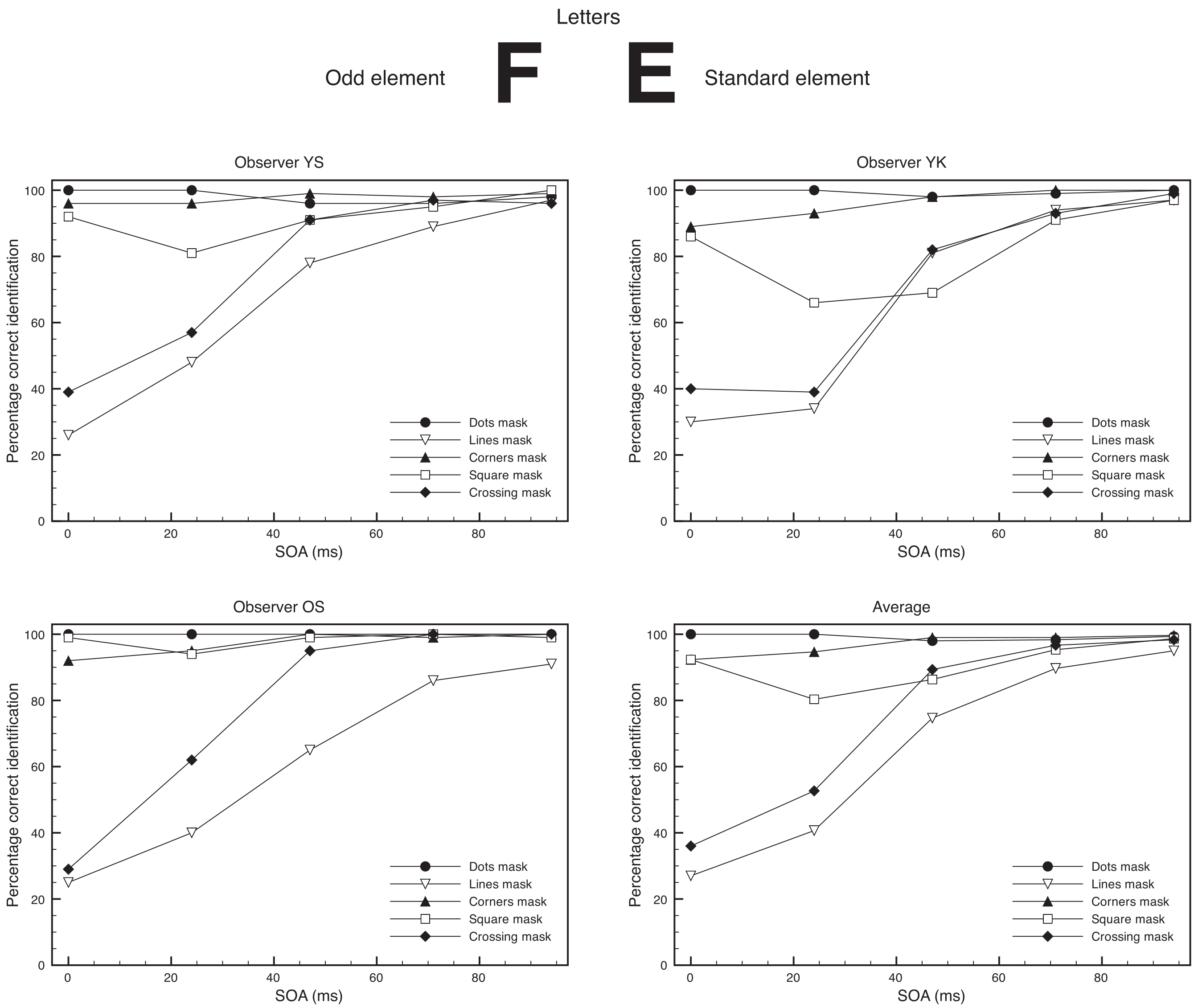

Figure 7. Masking functions from Experiment 1 for the letters. Results for each observer (and an average across observers) are shown in separate graphs. Within each graph, the different curves are for different masks. SOA = stimulus onset asynchrony.

They suggested that some spatial arrangements of target and mask stimuli would lead to camouflage of the target properties, much as in traditional integration masking. Such an arrangement would tend to lead to Type A masking functions. However, other target and mask combinations would not hide (and might even highlight) target properties and would tend to lead to Type B masking functions. Following the approach advocated by Francis and Cho (2005), we tested this idea by independently measuring the ability of the observers to report characteristics of the target when it is presented simultaneously with the mask.

Experiment 2: Visual Search

Method

The stimuli from the zero SOA condition were used in a visual search task, where the observer's task was to report whether an odd element was present. Additional displays were created that did not include an odd element in the target frame but instead consisted of four standard elements. If performance on the masking task depended on the temporal integration of the target and mask frames, then it should correlate highly with performance on the visual search task. However, if the shape of the masking function does not depend on temporal integration of the frames, the correlation between the studies should be close to zero.

For every target–mask combination, there were 96 trials where an odd element was present in the target frame and 96 trials where an odd element was absent in the target frame. On each trial, one of the displays appeared with a combination of target and mask elements. The display remained visible until the observer made a choice indicating whether the odd element was present or absent by pressing the appropriate key on a keyboard. The time between the onset of the display and the observer's response was recorded as reaction time. The same observers as in Experiment 1 also participated in Experiment 2.

Results

Incorrect responses (approximately 5.6% for odd element present and 2.5% for odd element absent trials) were discarded from further analysis. Figure 8A plots the percentage of correct responses from the masking experiment with a zero SOA against the reaction time for the target-present trials of the visual search experiment. Each data point corresponds to one of the target and mask combinations for 1 observer. The lines are best-fitting straight lines for each observer.

In agreement with the hypothesis, there is a strong correlation between the two data sets. Pearson correlation coefficients were −0.90, −0.87, and −0.87 for Observers YS, YK, and OS, respectively. Figure 8B plots the correlation coefficient between the visual search data set and the masking data set for each SOA. Separate curves are shown for each observer. As predicted, the correlation grows weaker (less negative) as SOA increases. Statistical significance of a correlation being different from zero for a two-tailed test with $p = .05$ would be found for a correlation beyond $r = -.444$. For 2 observers, the correlation fails to be significant with an SOA of 94 ms, which is close to the upper limit of SOAs for which temporal integration occurs (e.g., Di Lollo, 1980).

Discussion

The pattern of correlations replicates and extends the pattern found by Francis and Cho (2005). They also found a close correlation between reaction time on a visual search task and percentage of correct identification of the target at the zero SOA masking task. Overall, this is strong evidence that performance at the shortest SOAs on the backward masking experiment is determined by the appearance of the temporally integrated target and mask elements. In turn, this implies that the shape of the backward masking function depends on the properties of the temporally integrated target and mask elements. When the temporally integrated elements lead to a perceptual experience where the target is easily identified, the masking function is Type B. When the temporally integrated elements lead to a perceptual experience where the target is difficult to identify, the masking function is Type A.

General Discussion

The field of backward masking has a long history, and many previous studies have touched on some of the same topics we have discussed here. As discussed in the introduction, integration of the target and mask has long been recognized as a key part of backward masking. Likewise, the importance of the appearance of the combined target and mask stimuli has been recognized previously. Williams and Weisstein (1984) noted that the strength of masking at the shortest SOA correlated strongly with judgments of perceived depth produced by the combined target and mask elements. What is new in the present article is the proposed relationship between the appearance of the integrated target and mask stimuli and the shape of the masking function. This relationship has important implications for understanding the mechanisms of back-

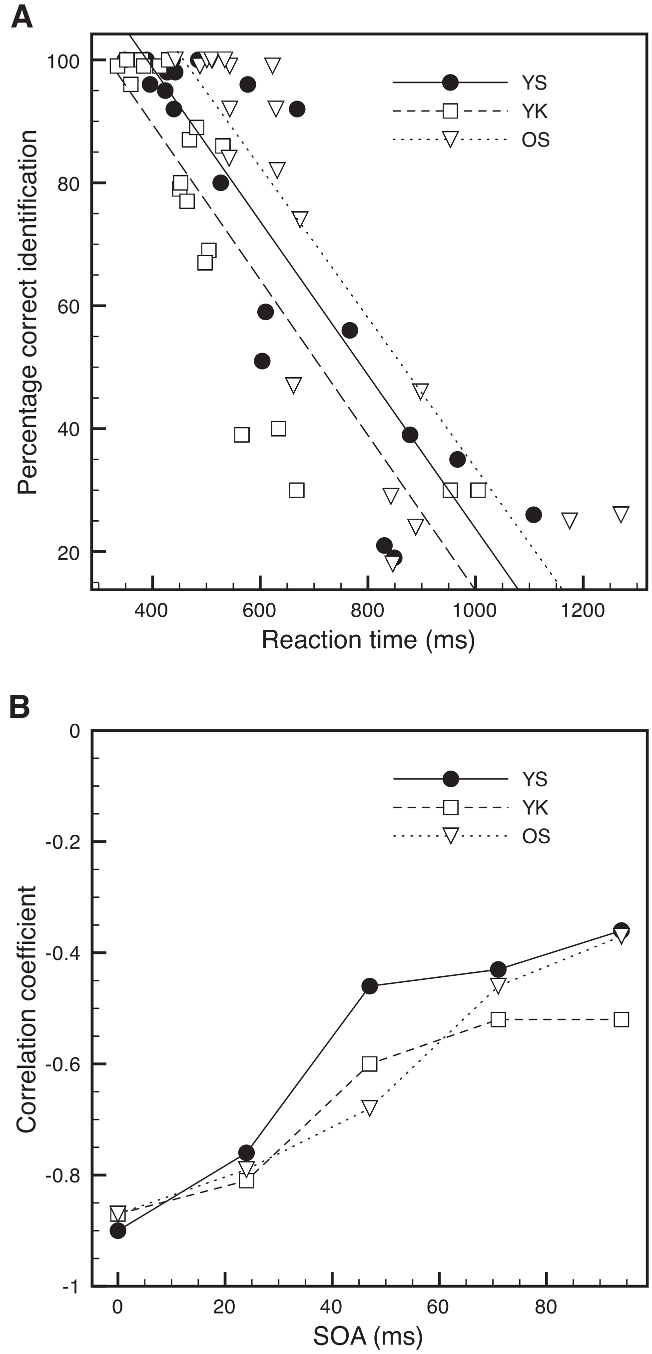

Figure 8. Correlations between the masking data from Experiment 1 and the visual search data from Experiment 2. Different symbols correspond to different observers. A: A scatter plot of the percentage of correct detections of the target location for zero stimulus onset asynchrony (SOA) from Experiment 1 against the reaction time needed to judge correct detection of the target in Experiment 2. Each point corresponds to one of the 20 target and mask combinations. The lines are the best-fitting straight lines, computed separately for each observer. B: The Pearson correlation coefficient between the reaction time data from Experiment 2 and the target detection percentage for differing SOAs from Experiment 1. The correlation is strongly negative for the shortest SOAs and grows weaker as SOA increases.

ward masking and for using backward masking to investigate other topics of perception and cognition.

Traditionally, Type A masking has seemed relatively easy to explain but Type B masking has seemed to be more challenging. Our proposal suggests that exactly the opposite is true. Francis (2000) identified three different mechanisms for producing Type B masking functions and showed that most inhibitory models use one of those methods. Thus, a Type B masking function can be explained in a fairly specified way. If you find a Type B masking function, you have a pretty good idea of how the mask interacts with the target, at least within the framework of these models. In particular, if a Type B masking function is found, then any integration effects at the shortest SOAs apparently do not mask the target or possibly make the target properties more easy to report than when the target is presented by itself.

Contrary to the established view, our analysis suggests that Type A masking is more complicated. In several different inhibition models, a strong mask can produce a Type A masking function without any integration effects at all (Francis & Herzog, 2004). However, it is also possible that the inhibitory effect of the mask is fundamentally Type B masking but that integration effects at the shortest SOAs hide features of the target, thereby leading to a Type A masking function. Without additional investigation, such as the method reported here, one cannot be sure if integration effects play any role in Type A masking.

Because of the ambiguity regarding the mechanisms that might produce Type A masking, researchers interested in using masking to explore other properties of cognition might be better served by restricting their investigations to situations that produce Type B masking rather than Type A masking. Such investigations may have their own share of difficulties, such as requiring measurement of the entire masking function, but the data could be analyzed within the framework of a specific model rather than the implicit unspecified model that is used in most studies with Type A masking functions.

For any use of masking to be theoretically justified, there must be better models of masking mechanisms. The experimental results make it clear that quantitative models of backward masking must include mechanisms for temporal integration. This is not easy for models that represent the target and mask stimuli without an explicit representation of space (Anbar & Anbar, 1982; Bachmann, 1994; Di Lollo, Enns, & Rensink, 2000; Francis, 2003; Weisstein, 1972). Such models typically have a single number that represents an activation corresponding to the target and another number that represents an activation corresponding to the mask. In these models, differences in the target and mask spatial structures can only be represented as differing magnitudes (or durations) of their activation values. Such a limited spatial representation means that these models cannot possibly deal with the integration effects described in our experiments. The lack of adequate spatial representation of visual stimuli has long been recognized as a deficiency in these kinds of models (Weisstein, 1972), and our analysis suggests that it cannot be ignored.

Models that do include a representation of visual space (Bridgeman, 1971, 1978; Bugmann & Taylor, 2005; Francis, 1997; Herzog, Ernst, Etzold, & Eurich, 2003; Ögmen et al., 2003) have a better chance of being able to deal with integration effects because they, at least potentially, can represent the spatial appearance of the integrated target and mask stimuli. Unfortunately, many of the current simulations of these models include only one dimension, whereas our data suggest that many effects require at least two-dimensional representations. Moreover, a representation of spatial information is not enough for the models to account for the data. These models need to be extended to include a model of object recognition that can compare the spatiotemporal patterns of activity between target and distracter elements as they integrate (or do not integrate) with the mask elements. The details of this process may change with task demands, criterion content, and observer differences. It has long been recognized that masking models need to consider the properties of both targets and distracters (Eriksen, 1980), but this critical factor has not been formally embedded within any theory of backward masking.

Thus, our experimental results suggest that an adequate explanation of backward masking effects will require a theory that includes both spatial and temporal processing. Although we have focused mostly on the need to incorporate spatial components into theories and models of backward masking, one could make a similar observation about a need to include temporal components in theories and models of spatial vision (e.g., Cao & Grossberg, 2005; Grossberg, 1997; Itti, Koch, & Niebur, 1998). Bringing together models of spatial and temporal vision may be a difficult task (Francis, 2007; Herzog, 2007), but it appears that without such a model, the mechanisms involved in backward masking cannot be understood. This conclusion is equally important for object-level descriptions of masking effects (Lleras & Moore, 2003; Moore & Lleras, 2005), as it indicates a need to consider the detailed spatial and temporal properties of the stimuli rather than just their object status (see also Lleras & Enns, 2006).

A model that includes a recognition system would likely be able to address related phenomena such as attentional blink, where recognition of a target item in a rapid serial visual presentation stream leads to reduced recognition of a subsequent target in the stream. It is interesting to note that the attentional blink literature has its own issues of masking functions. The attentional blink sometimes affects all items after the target, with a gradual reduction in the blink for later items, which is similar to the Type A masking function discussed here. Other times, the attentional blink does not affect the immediately following items in the stream but most strongly affects later items, which is similar to the Type B masking functions discussed here (Peterson & Juola, 2000). A key difference across the experimental paradigms is that the attentional blink is largely a forward masking phenomenon (an earlier item hinders recognition of a later item), whereas the masking functions discussed here involve backward masking (a later item hinders processing of an earlier item). Nevertheless, the two phenomena clearly operate at roughly the same time scale, and processes of integration and interruption have been proposed for both phenomena. We anticipate that attentional blink studies will provide some guidance on how to develop new models of backward masking. Because backward masking is used throughout many areas of cognitive psychology and cognitive neuroscience, the need for such a model is significant.

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