Pattern Masking and Visual Perception: Assessing the Effects of a Structure and Noise Mask using the General Recognition Theory

by

Krista R. Muis
B.A. (Honours), University of Waterloo, 1997

A Thesis Submitted in Partial Fulfilment of the
Requirements for the Degree of

MASTER OF ARTS

in the Department of Psychology

We accept this thesis as conforming
to the required standard

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Abstract

A new paradigm was used to test the effects of a structure and noise mask on the perception of visual stimuli. These effects were examined using the General Recognition Theory (GRT) framework (Ashby & Townsend, 1986) to investigate how stimulus dimensions affect each other during perceptual processing. Participants identified one level on each of two dimensions of a stimulus. The stimuli were arcs of varying curvature and radial lines of varying orientation. The effects of the masks were examined as a function of stimulus onset asynchrony, and perception of the stimuli was assessed for perceptual separability, perceptual independence, and decisional separability, as defined within the GRT. The results indicate that the structure mask had little effect on perception of the stimuli in terms of dimensional interactions. The noise mask, however, had a considerable effect on perceptual independence. The results are discussed in terms of a stochastic model of GRT (Ashby, 1989).

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Pattern Masking and Visual Perception:
Assessing the Effects of a Structure and Noise Mask
using the General Recognition Theory

Introduction

How does the human brain see the world? How do people see and how do they act on visual information? For years, researchers have been trying to answer a large number of questions regarding our visual system. We do know that, from the tiny, distorted, upside-down, two-dimensional retinal images projected upon the visual receptors, the visual system creates an accurate, richly detailed, three-dimensional perception of our world. Some of the earliest research conducted, that examined the initial stages and temporal parameters of perceptual processes, centered around two general fundamental questions. These questions involved assessing whether or not it was possible to isolate perceptual components, and whether or not it was possible to determine the primitive stages or mechanisms of the perceptual process (Breitmeyer, 1984).

How have researchers studied the spatial and temporal properties of visual perception? Historically, visual masking has played a leading role. Visual masking was developed as a methodological tool to delineate the temporal stages and parameters of the perceptual process (Breitmeyer, 1984). To this day, visual masking is a popular tool and has even been used in other research areas, such as memory. So what exactly is visual masking?

Visual Masking

Visual masking refers to the situation in which a briefly presented target stimulus is presented in close temporal and spatial relation to another briefly presented stimulus, called the mask (Matin, 1975). At a general level, visual masking refers to the reduction of the visibility of the target (Breitmeyer, 1984), hence, the detection or identification process is more difficult. The threshold for detection or identification is therefore increased (Bowen & Wilson, 1994).

Within a masking paradigm, two temporal types of masking may be used: forward masking and backward masking. Forward masking refers to the case in which the mask precedes the target, and backward masking refers to the case in which the target precedes the mask (Matin, 1975). Two general physical types of masking may be used: masking by light and pattern masking. Masking by light is a form of visual masking in which a briefly flashed, uniformly lit field obscures the visibility of a target, presented before or after the mask (Breitmeyer, 1984). For pattern masking, three specific types of masks, defined by how they are constructed, may be used: a contrast mask; a noise mask; or, a structure mask. Figure 1 illustrates the three types of pattern masking.

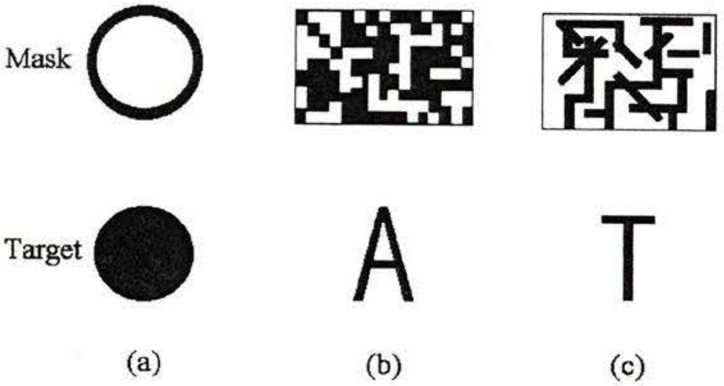


Figure 1. Examples of mask and target stimuli typically used for a (a) metacontrast and paracontrast mask, (b) noise mask, and (c) structure mask (Breitmeyer & Ganz, 1976).

A contrast mask is a mask in which the contours of the mask do not overlap but are spatially contiguous with the contours of the target (Breitmeyer & Ganz, 1976). A paracontrast mask refers to the case in which the mask precedes the target and a metacontrast mask refers to the case in which the target precedes the mask. A noise mask refers to the case in which the mask elements and contours, although spatially overlapping those of the target, are designed to bear little, if any, structural relationship to the target contours (Breitmeyer, 1984). Finally, a structure mask refers to the case when the overlapping contours of the mask are designed so that they structurally resemble the contours of the target in some of its figural characteristics, such as orientation, curvature, or angularity (Breitmeyer & Ganz, 1976).

The three pattern masks described can generate four fundamental types of masking effects, and are obtained as a function of the stimulus onset asynchrony between the target and mask. Stimulus onset asynchrony (SOA) is defined as the temporal interval separating the onsets of the target and mask. Thus, an SOA of zero represents the condition in which the target and mask are presented at the same time. Negative SOA values indicate forward masking and positive SOA values indicate backward masking. The four types of masking effects are illustrated in Figure 2.

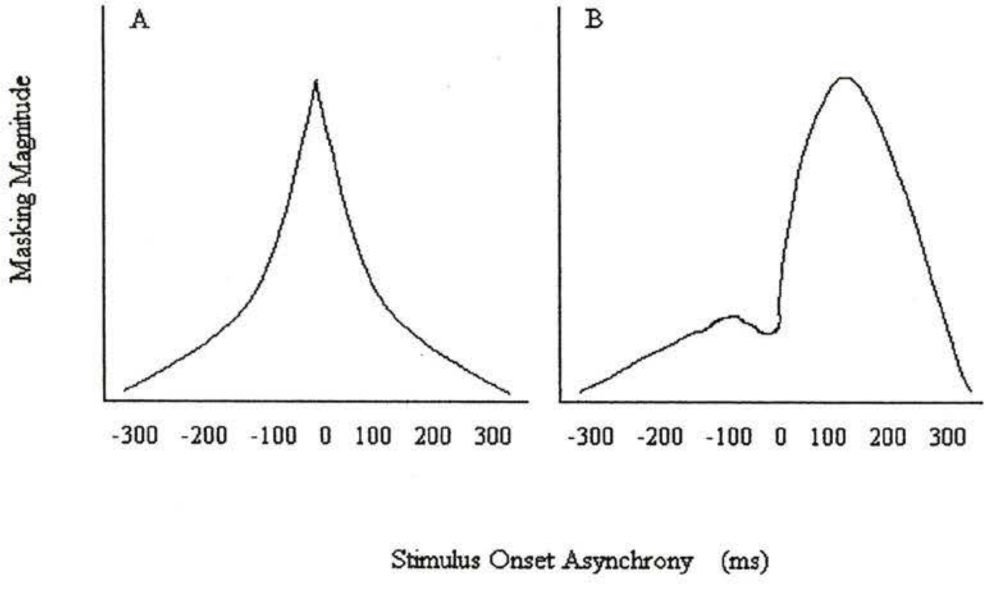


Figure 2. Functions typically obtained in visual masking. (a) Type A monotonic forward and backward functions; (b) Type B nonmonotonic forward and backward functions (Breitmeyer, 1984).

Figure 2(a) illustrates the typical monotonic, Type A forward, and monotonic, Type A backward masking functions. The Type A forward masking function is represented by the left side of the function in Figure 2(a), from -300 milliseconds (ms) to zero ms, and the Type A backward masking function is represented by the right side of the function, from zero ms to 300 ms, in Figure 2(a). Figure 2(b) illustrates the typical non-monotonic, Type B forward, and non-monotonic, Type B backward masking functions. The Type B forward masking function is represented by the left side of the function, from -300 ms to zero ms, and the Type B backward masking function is represented by the right side of the function, from zero ms to 300 ms, in Figure 2(b).

Both the paracontrast and metacontrast mask can produce either a Type A function or Type B function (Lefton & Newman, 1976; Weisstein, 1972). The type of paracontrast function one obtains depends upon the experimental task. If the task is brightness judgement or contour discrimination, the Type B function is obtained for both binocular presentation of both target and mask (presented to both eyes) (Weisstein, 1972) and dichoptic presentation (target presented to one eye, mask presented to the other) (Kolers & Rosner, 1960). Further, the magnitude of masking effect for the Type B function increases as the mask energy (measured by stimulus luminance and presentation duration) increases relative to the target energy (Weisstein, 1972), and decreases as the spatial separation between the target and mask increases (Kolers & Rosner, 1960). If, however, the task is target detection, a Type A function is obtained (Lefton & Newman, 1976).

Like the paracontrast mask, the metacontrast mask produces a Type B function when the task is to judge stimulus brightness or contour discrimination (Weisstein, 1972). The metacontrast mask, however, produces a Type A function when the task is target detection (Lefton & Newman, 1976). Furthermore, when the task is to judge stimulus brightness or contour discrimination but target energy is less than mask energy, a Type A function is obtained but shifts from a Type A function to a Type B function when the target energy is equal to or greater than the mask energy (Weisstein, 1972). Moreover, as with the paracontrast mask, the magnitude of masking effect for the Type B function decreases as the spatial separation between the outer contour of the target and the inner contour of the mask increases (Weisstein & Growney, 1969).

The noise mask, in contrast, produces a strong Type A forward and backward masking function when the task is target identification (Schiller & Smith, 1965). Moreover, the magnitude of the masking effect is stronger at higher mask intensities, relative to target intensity, and as the relative spatial overlap of the mask increases as the target size remains constant, the masking effect also increases (Schiller, 1966). When the target and noise mask are presented dichoptically, a Type A function is still obtained, but the magnitude is considerably weaker when a forward noise mask is used when compared with the backward effect (Turvey, 1973). Furthermore, in the dichoptic condition, the intensity of the mask does not appear to be an important parameter when manipulating the magnitude of the masking effect (Turvey, 1973).

For the structure mask, especially when the mask energy is greater than the target energy, strong Type A forward and backward masking functions are obtained when the task is target detection (Sekuler, 1965). When the target energy is greater than the mask energy, however, a Type B backward masking function is obtained when the task is target identification (Turvey, 1973). Furthermore, under dichoptic viewing conditions, a Type B backward masking function can be obtained when the target energy is below or above the mask energy (Turvey, 1973). Table 1 provides a summary of the type of function that each type of mask produces under the various conditions.

Table 1

Type of masking function obtained, either Type A or Type B, as a function of task parameters and stimulus characteristics

	Experimental Manipulations that Produce a Type A Function	Experimental Manipulations that Produce a Type B Function
Type of Mask		
Paracontrast	* Target detection task	* Brightness judgement task * Contour discrimination task
Metacontrast	* Target detection task * Target energy < mask energy	* Brightness judgement task * Contour discrimination task * Target energy > mask energy
Noise	* Target identification task	(none)
Structure	* Target detection task * Target identification task * Target energy < mask energy	* Dichoptic presentation of target and mask * Target energy > mask energy

The next section of this paper presents a new paradigm from which to test the effects of visual masking. An experiment is then presented that assesses the effects of target and mask similarity, when a structure mask is used, and that assesses the effects of using a noise mask, when the target and mask share no common elements or contours. A comparison is then made between the effects of the structure mask and the noise mask within this new paradigm. Specifically, I am interested in examining how a structure mask and a noise mask interact with the perception of visual stimuli within the General Recognition Theory (GRT) framework (Ashby & Townsend, 1986). If one is interested in examining the perception of visual stimuli, and one uses a mask to make the detection or identification process more difficult, it is necessary to first assess whether or not the presentation of the mask alters the outcome of perception. In other words, one needs to assess whether or not the presentation of the mask interrupts or interacts with the perceptual processing of the target item, and what the effect of the interruption or interaction is. The question, then, is does the presentation of a mask alter the perception of the visual stimuli to the degree that the outcome of perception, when a mask is presented, is different than the outcome when a mask is not presented. This question can be assessed using the GRT framework to examine how stimulus dimensions affect each other during perceptual processing.

General Recognition Theory

How do elementary dimensions of a stimulus combine and interact during perceptual processing? Researchers have studied whether variations in one dimension affected the perceptual processing of another dimension (Garner, 1974). Quite commonly, researchers characterized perceptual dimensions according to whether the dimensions were separable or integral (Shepard, 1964). Until recently, there was no unified theoretical framework that organized and related the various operational constructs of dimensional interactions. Ashby and Townsend (1986; see also Kadlec & Townsend, 1992b) formally introduced a theory of perceptual identification, called the General Recognition Theory (GRT), which provides rigorous definitions of separability, integrality, and independence, and further relates these definitions to observable behaviour.

The GRT can be viewed as an extension of signal detection theory (Green & Swets, 1966) to the multidimensional situation. This paradigm involves a task in which participants are presented simple stimuli (see below) and are required to identify two or more dimensions of the stimuli. GRT assumes that when a stimulus is presented to the observer, the output of the perceptual process can be represented as a point in a multidimensional space. The same stimulus, however, does not always elicit the same perceptual effect over trials. Thus, if the perceptual space is two dimensional, then the complete set of perceptual effects for a given stimulus is represented by a unique bivariate probability distribution (Ashby & Townsend, 1986).

Consider an experiment in which the stimuli are constructed from two physical components, A and B, with two levels of each. For example, the stimuli might be semicircles of varying size with radial lines of varying orientation. Thus, a given stimulus is denoted as A_iB_j, where 'i' indicates the level of component A and 'j' indicates the level of component B. If one combines all levels of A with all levels of B, one obtains a feature-complete factorial design. With two levels of each, the resulting four stimuli are A_1B_1,

A_1B_2, A_2B_1, and A_2B_2. In GRT, component A is associated with perceptual dimension x and component B is associated with perceptual dimension y. The joint distribution (probability density function) of perceptual effects on trials when stimulus A_iB_j is presented, is denoted $f_{ij}(x,y)$ (Ashby & Townsend, 1986). For a convenient way of examining the joint distributions, if one were to cut a cross section of the density at a constant level of likelihood, and examine them from an ariel point of view, one would obtain what are called equal likelihood contours. Figure 3 illustrates the equal likelihood contours for the entire stimulus set, given in the x-y space.

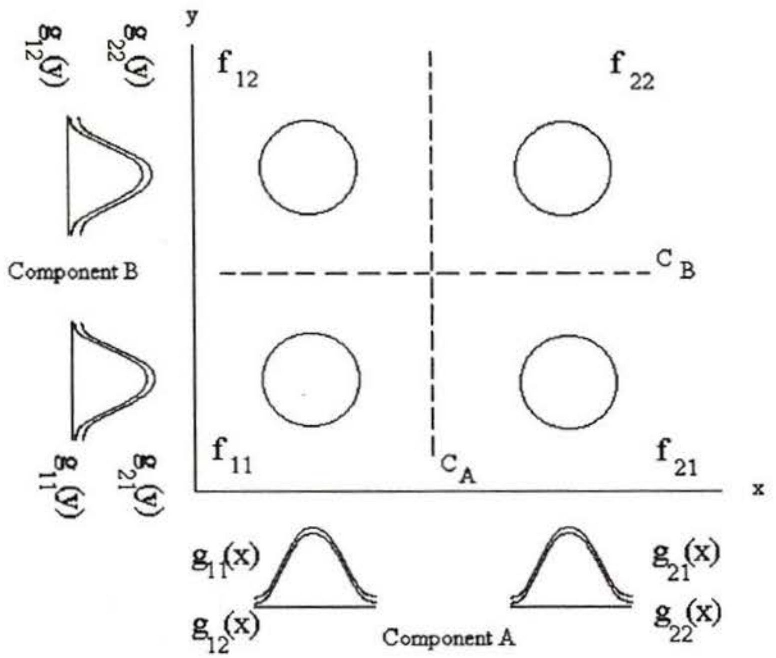


Figure 3. Illustration of the contours of equal likelihood associated with the stimuli A_1B_1, A_1B_2, A_2B_1, and A_2B_2, from an ariel point of view.

The joint perceptual distributions in Figure 3 describe the simultaneous effects of both components in a given stimulus. From these joint perceptual distributions we define marginal distributions, which describe the percepts associated with only one component in a given stimulus. The perception of the other component is thus ignored. The notation for the marginal distribution for the perceptual effect of component A in stimulus A_iB_j is given by $g_{ij}(x)$, and $g_{ij}(y)$ for component B. These marginal distributions are also illustrated in Figure 3 along the left and bottom margins of the x-y space.

In an identification experiment, GRT assumes that for the decision process the observer divides up the perceptual space into four regions, using two decision boundaries. The decision bounds are the broken lines separating the regions in Figure 3. Each region is then assigned a response. Any perceptual effect, (x,y), falling into the response region associated with stimulus A_iB_j would then lead to an $R_{A_iB_j}$ response. Thus, on each trial, the participant determines which region the perceptual effect is located and then gives the associated response.

Within the GRT framework, several important concepts associated with dimensional interactions are defined. The three principal theoretical definitions are that of perceptual independence, perceptual separability, and decisional separability (Ashby & Townsend, 1986). For simplicity, the following definitions will assume a two dimensional case, though the results generalize to higher dimensional cases (see, e.g., Kadlec & Townsend, 1992b).

DEFINITION 1. Perceptual independence (PI) of components A and B holds if and only if the perceptual effects associated with component A are statistically independent of the perceptual effects associated with B. That is, if and only if

$$f_{ij}(x,y) = g_{ij}(x)g_{ij}(y),$$

for all values of x and y (Ashby & Townsend, 1986).

When the perceptual distributions are normal, perceptual independence occurs if and only if the perceptual effects of components A and B are uncorrelated. The equal likelihood contours for Gaussian densities whose components are independent are either circles, if the variances are equal, or ellipses with the major and minor axes parallel to the coordinate axes. If a correlation exists, the contours will be ellipses that are tilted either to the right, representing a positive correlation, or to the left, representing a negative correlation. If correlated, the components are said to be perceptually dependent. It is important to note that perceptual independence is a property of a single stimulus, and thus is at a more ‘micro’ level than the following definitions, which are at a more ‘macro’ level.

DEFINITION 2. Component A (B) is perceptually separable (PS) from component B (A) if and only if the perceptual effect of A (B) does not depend on the level of component B (A). That is, if and only if

$$g_{i1}(x) = g_{i2}(x), \text{ for } i = 1 \text{ and } 2, \text{ for A},$$

for all values of x, and

$$g_{1j}(y) = g_{2j}(y), \text{ for } j = 1 \text{ and } 2, \text{ for B},$$

for all values of y (Ashby & Townsend, 1986).

Further, if component A is perceptually separable from component B and component B is perceptually separable from component A, then components A and B are said to satisfy *mutual perceptual separability*. If components A and B are not perceptually separable, then they are *perceptually integral*. Finally, if A is perceptually separable from B, but B is not perceptually separable from A (or vice versa), then an *asymmetric perceptual separability* exists (as well as an *asymmetric perceptual integrality*).

DEFINITION 3. Component A (B) is *decisionally separable* (DS) if and only if the decision about A (B) does not depend on the magnitude of the perceptual effect associated with component B (A). I.e., the decision bound C_A (C_B) for A (B) is parallel to the Y axis (X axis) (Ashby & Townsend, 1986).

A participant obeying decisional separability will decide that A is at level 2, for example, if x is greater than some criterion value C_A, regardless of the value of y. It is important to note here that for both perceptual separability and decisional separability, one component may be separable from the other component, but the converse may not be true. Furthermore, since perceptual separability and decisional separability are unrelated, it is possible for one to hold in the absence of the other.

The question addressed in this paper is whether perceptual independence, perceptual separability, and decisional separability (though not of primary interest here) of stimulus dimensions will be affected by the presentation of a backward structure mask and a backward noise mask, and if so, how the effect of these two types of masks may differ. In order to make any predictions, a comprehensive theory of visual masking must first be discussed. The most popular, widely used, and well-supported theory of visual masking is the transient-sustained theory (Breitmeyer & Ganz, 1976). Other theories of visual masking will not be discussed here, since it is not of interest in the present experiment to test these theories. See Weisstein, Ozog, and Szoc (1975), and Francis (1997) for other theories of visual masking.

The Transient-Sustained Theory of Visual Masking

Breitmeyer and Ganz (1976) offered a visual masking hypothesis that incorporates two previous visual masking hypotheses and research based on psychophysical and neurophysiological properties of the visual system. These are the integration hypothesis, the inhibition hypothesis, and the spatiotemporal response properties of transient and sustained cells in the visual system. According to the integration hypothesis, due to persistence of the sensory response to a brief stimulus presentation (Efron, 1970a), sensory representations of the target and mask can combine to form a representation in which the mask obscures the target. An integration effect is most prominent at an SOA of 0 ms, at which point the target and mask are seen as one stimulus, and decreases over a short SOA range (Breitmeyer & Ganz, 1976). This hypothesis can explain both forward and backward masking effects with respect to the type of masking function obtained, since the integration of information from target and mask will occur regardless of presentation order.

According to the inhibition hypothesis, target information processing is interrupted by the presentation of the mask. The time at which the mask is presented and what the task is will both influence the magnitude of the masking effect. For example, if the task requires a low level of processing, such as target detection, the magnitude of masking effect will decrease more quickly as SOA increases than if the task required a higher level of processing, such as pattern identification. Thus, the activity of the cells responding to the target is inhibited by the presentation of the mask (Breitmeyer & Ganz, 1976).

The transient-sustained visual masking model classifies the visual system as a system with two parallel pathways which are in a complementary relationship. These two parallel pathways are the magnocellular pathway and the parvocellular pathway. The cells in the magnocellular pathway have a short response latency, conduct information at a relatively rapid rate, fire in a transient fashion, and are particularly sensitive to abrupt stimulus onset and offset (Zeki, 1993). The cells in the parvocellular pathway have a long response latency, conduct information at a relatively slow rate, and continue to fire in a sustained fashion (Zeki, 1993). Because of the response properties of these two types of cells, they have been termed transient and sustained cells, respectively.

The transient-sustained dichotomy is applied to visual masking in the following manner. The integration hypothesis states, as previously mentioned, that due to the persistence of the sensory response to a brief stimulus presentation, successive target and mask stimuli interact in such a way as to lower the signal-to-noise ratio (an increase in noise from the mask) within the visual system. The target and mask combine their excitatory effects, forming a blend of information at a particular stage of processing (Breitmeyer & Ganz, 1976). Again, the degree of interaction that occurs is assumed to decrease as a function of increasing SOA, for Type A masking.

The inhibition hypothesis states that target information processing is interrupted by the presentation of the mask. This can occur in one of two ways, either through interchannel inhibition or intrachannel inhibition. Interchannel inhibition occurs when the transient neurons inhibit the activity of the sustained neurons. Intrachannel inhibition occurs when the neural activity generated by the target and mask share common transient and sustained pathways, when the target and mask are spatially overlapping, and hence the inhibition occurs between cells of the same type (Breitmeyer & Ganz, 1976). Figure 4 illustrates how the time course of the transient and sustained channels possibly interact at different SOAs.

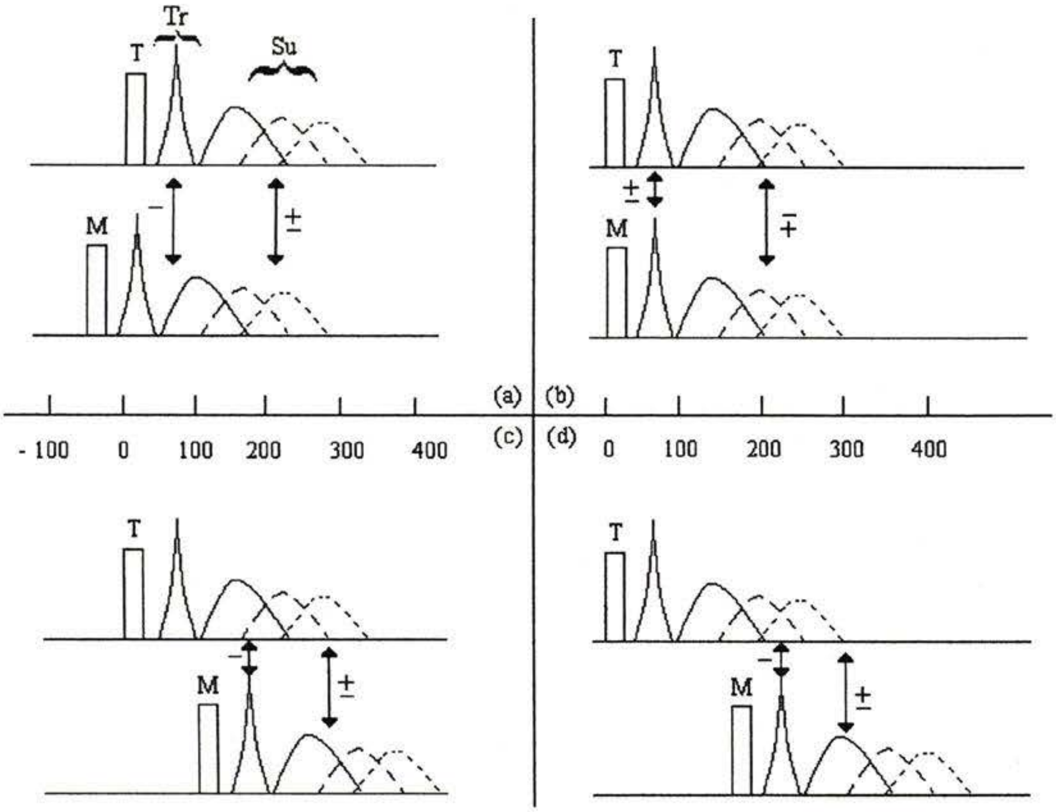


Figure 4. The interaction of target (T) and mask (M) neural activity when (a) the mask precedes the target, (b) the mask and target are presented simultaneously, (c) the mask is presented after the target at a short SOA, and (d) the mask is presented after the target at a long SOA. The transient channels are indicated by the short-latency, spiked responses, and the sustained channels are indicated by the inverted u-shaped curves (Tr = transient and Su = sustained). Arrows with a positive sign indicate that the interaction is one of sensory integration and arrows with a negative sign indicate that the interaction is inhibitory (Breitmeyer & Ganz, 1976).

The logic of the inhibitory interaction between target and mask is as follows. First, both the target and mask activate transient and sustained channels. Within a class of cells, either transient or sustained, intrachannel inhibition may occur, or between the two classes of cells, interchannel inhibition may occur (Breitmeyer & Ganz, 1976). Both intrachannel and interchannel inhibition are reciprocal, thus the information from the mask can inhibit, or interrupt, the processing of the target and vice versa. Where and when the inhibition or interruption of the information occurs is a function of SOA. For example, if the target precedes the mask at a short SOA, as in Figure 4(c), an interchannel inhibition can occur between the transient cells of the mask and the sustained cells of the target. An intrachannel inhibition may also occur between the sustained cells of both the target and mask. The bidirectional arrows in Figure 4 indicate that this inhibition is reciprocal between the target and the mask (Breitmeyer, 1984).

The integration interaction, on the other hand, occurs only between cells of the same type (Breitmeyer & Ganz, 1976). Thus, only intrachannel integration occurs between the transient cells of the target and mask or between the sustained cells of the target and mask. This is illustrated in Figure 4, with the positive signs indicating the integration of information and the bidirectional arrows indicating a reciprocal relationship. For example, if the target precedes the mask at a longer SOA, as in Figure 4(d), an intrachannel integration will only occur between the sustained cells of the target and mask. This integration is said to occur because of the sharing of common retinotopically organized pathways (Breitmeyer, 1984). Furthermore, intrachannel integration occurs between transient cells only when the target and mask are presented simultaneously (Figure 4(b)), but may occur in sustained cells from the point at which the mask is presented no more than 300 ms before or after the onset of the target (Breitmeyer & Ganz, 1976).

Both the integration hypothesis and the inhibition hypothesis, based on research conducted by Turvey (1973), Weisstein (1971), and others, have been used to explain how the three types of pattern masks can generate the four fundamental types of masking functions, namely, the Type A forward and backward masking functions, and the Type B forward and backward masking functions. To begin, Breitmeyer and Ganz (1976) distinguished between two general types of forward masking; masking with spatially overlapping patterns such as a structure mask or a noise mask; and, masking with spatially adjacent patterns, such as the paracontrast mask. In both types of forward masking, the mask's transient activity cannot interact in any way with the target activity, as seen in Figure 4(a). Reciprocal inhibition between the target's transient activity and the mask's sustained activity, on the other hand, can. Furthermore, for the forward structure and noise mask, the sustained channels for both the target and mask may mutually inhibit each other (intrachannel inhibition), and may also integrate (intrachannel integration). For the paracontrast mask, on the other hand, only intrachannel inhibition, and not intrachannel integration, can occur, since the mask and target patterns do not spatially overlap (Breitmeyer, 1984).

When the target and mask are presented simultaneously, as seen in Figure 4(b), both intrachannel inhibition and intrachannel integration can occur in both the transient and sustained activity of the target and mask when either a structure or noise mask is presented (Breitmeyer, 1984). When using a spatially adjacent contrast mask that is presented simultaneously with the target, however, only intrachannel inhibition contributes to the overall masking effect (Breitmeyer, 1984).

When the target precedes the mask by 100 ms, as seen in Figure 4(c), for the structure and noise mask, the transient activity of the mask and the earliest sustained activity of the target can interact via mutual interchannel inhibition (Breitmeyer, 1984). Intrachannel integration of sustained activity can also occur for both the structure and noise masks at a 100 ms SOA (Breitmeyer, 1984). For the metacontrast mask at a 100 ms SOA, the transient activity of the mask can interact with the earliest sustained activity of the target, thus interchannel inhibition can occur, and the sustained activity of the target and mask can mutually inhibit one another, thus intrachannel inhibition may also occur (Breitmeyer, 1984).

When the target precedes the mask by 160 ms, as seen in Figure 4(d), for the structure and noise mask, interchannel inhibition can occur between the transient activity of the mask and the sustained activity of the target. Moreover, very little intrachannel integration will occur, if any at all, between the sustained activity of the target and mask for this SOA because processing of the target is almost complete (Breitmeyer, 1984). Finally, when the target precedes the metacontrast mask by 160 ms, interchannel inhibition can occur between the transient activity of the mask and the sustained activity of the target, but very little intrachannel inhibition will occur between the sustained cells of the target and mask (Breitmeyer & Ganz, 1976). In summary, for the paracontrast and metacontrast masks, intrachannel inhibition among the transient or sustained pathways can occur, as well as interchannel inhibition between the transient and sustained pathways, but not integration (Breitmeyer, 1984). For the noise and structure masks, intrachannel inhibition, interchannel inhibition, and intrachannel integration can occur (Breitmeyer, 1984).

For the present experiment, the type of masking function that would be obtained under binocular viewing conditions, either a Type A or Type B, needs to be determined in order to make any predictions as to the degree of interaction (magnitude of masking effect) that would be expected as a function of SOA. In the experiment, a backward structure mask and a backward noise mask was used. To assess whether a Type A or Type B function will be obtained, stimulus and mask luminance need to be assessed only for the structure mask condition, since the noise mask produces a Type A function under many conditions (Schiller, 1966). The target stimuli for the experiment are shown in Figure 5(a) and the structure mask is shown in Figure 5(b).

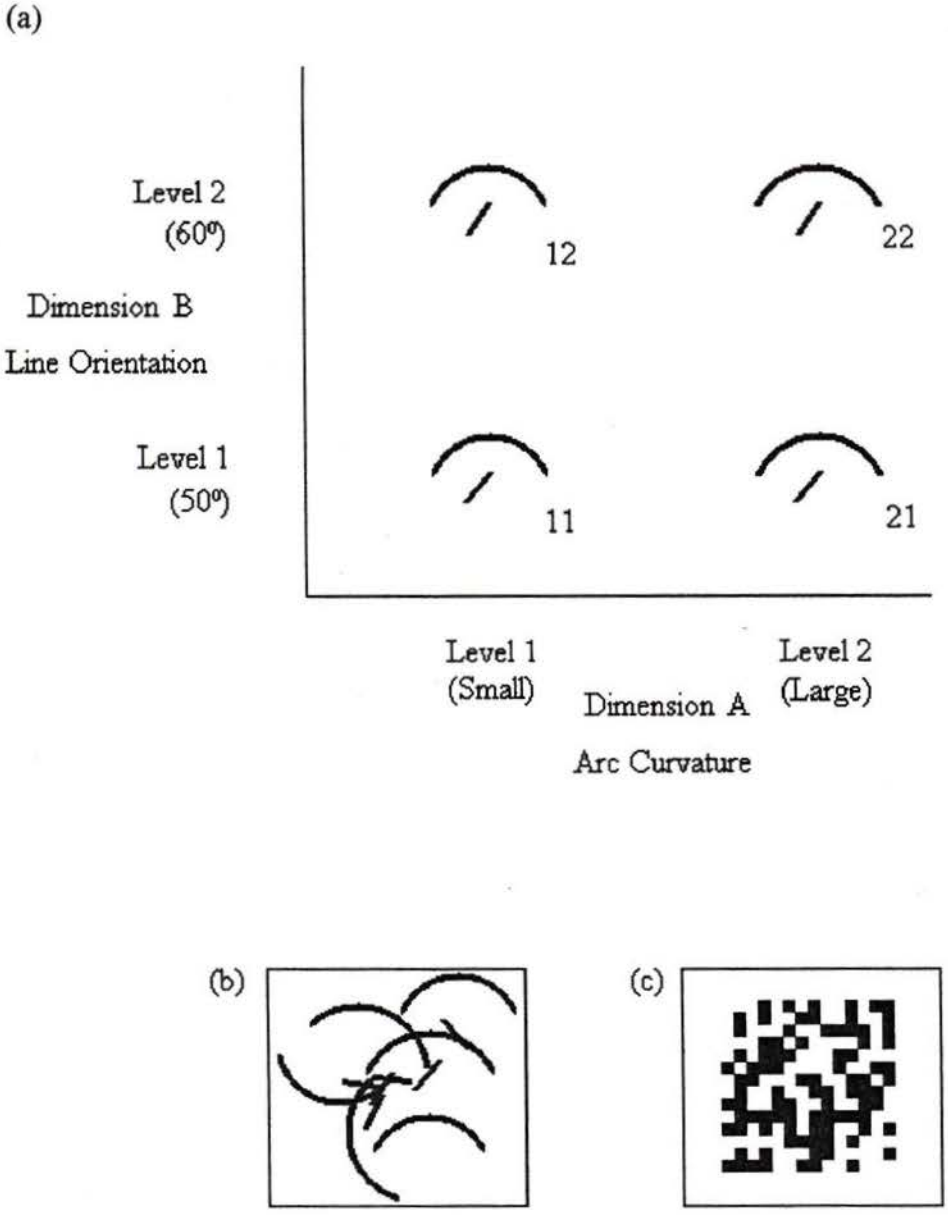


Figure 5. (a) Stimuli used in experiment (numbers indicate correct responses), (b) structure mask used in experiment, and (c) noise mask used in experiment.

As previously mentioned, if the target energy, as measured by luminance and presentation duration, is less than the structure mask energy, a Type A function is obtained (Sekuler, 1965), but if the structure mask energy is less than target energy, a Type B function is obtained (Turvey, 1973). For this experiment, because both target stimulus and structure mask have equal energy, since they are both presented for the same duration and have equal luminance (see method section for more details), either a Type A or B function could be obtained. But since the structure mask is considerably larger than the target, and hence is more likely to obscure the target, I would predict that a Type A function is obtained. Therefore, I would predict that for both the structure mask and noise mask, a Type A function is obtained.

Both the integration hypothesis and the inhibition hypothesis are therefore used to make predictions since both the structure mask and noise mask can inhibit as well as integrate with target processing (Breitmeyer, 1984). The integration hypothesis predicts, for a backward mask presented 100 ms or longer after the target, that the mask's sustained activity would integrate with the target's sustained activity, therefore blending processing information (see Figure 4(c) and 4(d)). The inhibition hypothesis predicts that the transient and sustained activity of the mask would inhibit the sustained activity of the target. What is of most interest is whether the excitatory and inhibitory effects alter the perception of the target item in terms of independence and separability of the stimulus dimensions.

If it is the case that these effects do not alter perception when either a structure or a noise mask is presented, then those masks may be used to make any task of interest more difficult in any context in which perception is studied. The sole purpose of a mask in many studies is to simply make the task more difficult. If it is demonstrated here that both masks do not alter perception, then either the structure or noise mask can be used freely to make the identification process more difficult without having to consider any other effects that the masks may have. If it is the case, however, that one or both masks alter perception, then the type of mask that does interact with the target should not be used if the original purpose of the mask was to simply make the task more difficult. The perception of the stimulus in this case, when an interaction occurs, is no longer a "pure measure" of perception, since the mask alters the perception of the stimulus. Thus, it is necessary to determine whether a mask simply makes the task more difficult or whether a mask alters the perception of the target item in terms of independence and separability. This can be assessed using GRT (Ashby & Townsend, 1986). The question now is how the mask might alter the perception of the stimulus dimensions.

Stochastic GRT

Ashby (1989) proposed a dynamic version of the GRT (Ashby & Townsend,1986) based on a notion that was previously associated with signal detection theory, that is, the notion of a processing channel. The idea is that for each component of a stimulus there is a processing channel that is tuned to that component of the stimulus, and all processing channels for that stimulus can mutually interact. The array of mutually interacting channels is described as a parallel processing system and is illustrated, for the case of two components in a stimulus, in Figure 6.

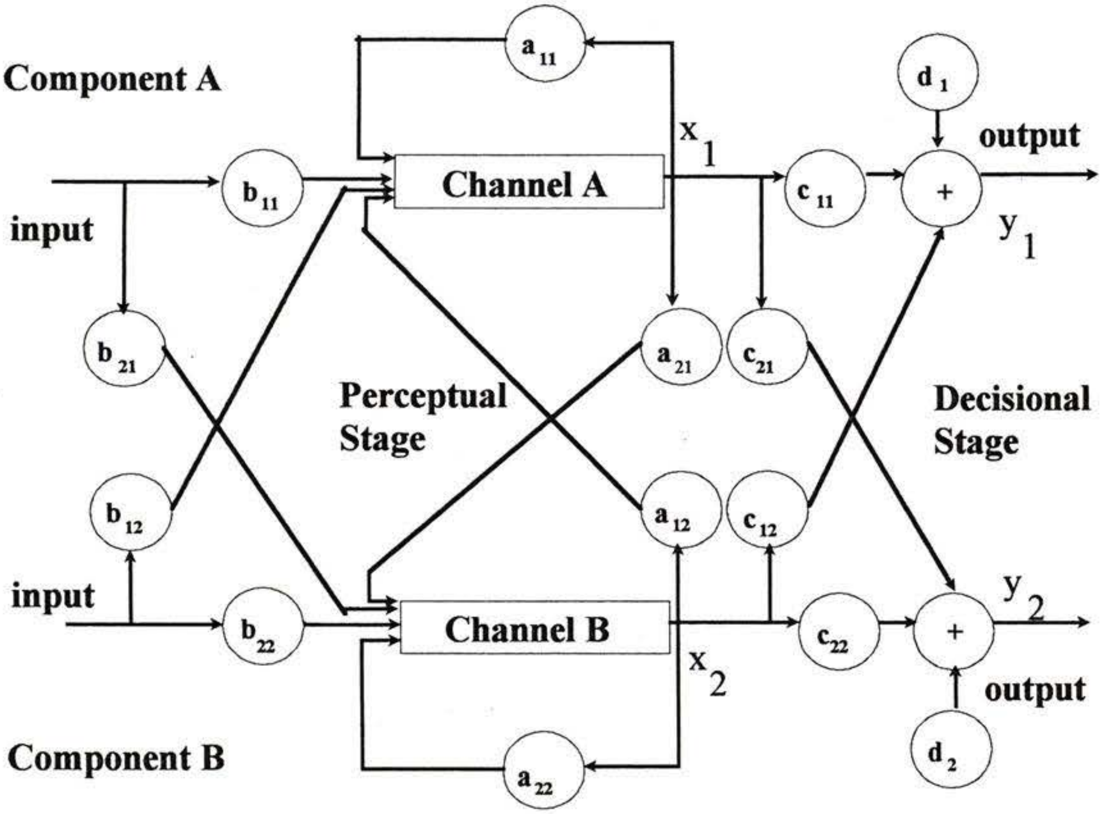


Figure 6. The connections between the two hypothetical processing channels as defined by stochastic General Recognition Theory (Ashby, 1989).

Focusing solely on the perceptual processing stage, each processing channel is composed of three parts. These consist of the input lines, with weights represented by the b_{ij}, the perceptual processing channels, with interaction and feedback weights represented by the a_{ij}, and the output lines, with weights represented by the c_{ij}. The outputs of the perceptual channels, denoted by x_1 and x_2, represent the perceptual effects of the two stimulus components at a particular point in time. The decision process then occurs, and the outputs of that process are denoted by y_1 and y_2. Because of the decision process, the system outputs may not be equal to the perceptual effects prior to the decision process (Ashby, 1989).

Perceptual separability, perceptual independence, and decisional separability are directly linked to the processing channels in the following manner. Ashby (1989) demonstrated that, for perceptual separability to hold, it is a sufficient condition that there is no crossing of the input lines and no crosstalk between the channels. Specifically, the weights for b_{12}, b_{21}, a_{12}, and a_{21} would equal zero. Therefore, the input to each channel would be processed only by that separate channel. For example, information about component A would be processed only through b_{11} and a_{11}, but not through b_{21} or a_{21}. If processing occurred along both b_{12} and b_{21}, then perceptual separability fails in both of the stimulus components. Furthermore, if processing occurred in only one of the inputs, say b_{12}, then perceptual separability would fail for component B.

For perceptual independence to hold, Ashby (1989) demonstrated that when lateral processing along a_{12} and a_{21} does not occur between the channels, perceptual independence holds. Conversely, perceptual independence fails when lateral processing does occur. The weights for a_{12} and a_{21}, then, equal zero when perceptual independence holds, but are nonzero when perceptual independence does not hold. Furthermore, note that for each channel, feedback is given as input to itself if a_{11} and a_{22} are nonzero at this particular stage of processing.

Decisional separability holds when processing does not occur along the two outputs in c_{12} and c_{21}. In this case, the weights for c_{12} and c_{21} would equal zero. If processing occurred along c_{12} and c_{21}, however, decisional separability fails in both of the stimulus dimensions. Similar to perceptual separability, if processing occurred along only one of the outputs, say c_{12}, then decisional separability would fail for component B. In sum, perceptual separability holds when there is no crossing of the input lines or crosstalk between the channels, perceptual independence holds when there is no crosstalk between the channels, and decisional separability holds when there is no crossing of the output lines (Ashby, 1989).

Predictions

This model can be related to interchannel inhibition, intrachannel inhibition, and intrachannel integration in the following manner. To begin, the processing channels for both stimulus components in the target and in the structure mask consist of transient and sustained cells. For the structure mask, because the mask is presented in the same spatial location as the stimulus, the transient and sustained cells of the mask can interact with the transient and sustained cells of the stimulus. This can occur because both the stimulus and structure mask, which are composed of the same components, are processed in the same processing channels.

Because information is processed over time, one is able to identify which types of interactions could occur at which stages of processing in the channels. Specifically, when the mask is presented after the target, the transient activity of the mask would inhibit the sustained activity of the target which would make the task more difficult and therefore a decrease in accuracy would occur. Moreover, this interchannel inhibition between the transient activity of the mask and sustained activity of the target could occur at the input stage, if the mask is presented within a critical time period, and hence could affect perceptual separability. Interchannel inhibition could affect the system such that it is necessary to process the information for both components in both channels, via b_{21} and b_{12}, in order for processing to be completed. Thus, perceptual separability would fail for both components if processing occurred along b_{21} and b_{12}. If, however, interchannel inhibition does not prompt the system to process along b_{21} and b_{12}, then perceptual separability would hold for both components.

Both intrachannel inhibition and intrachannel integration would occur between the sustained cells of the structure mask and the sustained cells of the target. Both types of intrachannel interactions would occur at a later stage of processing and hence would occur within the processing channels. At this stage of processing, information from the outputs of these channels can feed back information to itself via a_{11} or a_{22}. Both intrachannel inhibition and intrachannel integration along a_{11} or a_{22} would lead to an increase in task difficulty, but neither would affect perceptual independence. Instead, perceptual independence would be affected if processing occurred along a_{21} or a_{12}.

First, intrachannel inhibition and intrachannel integration between the sustained cells of the target and mask may behave similarly to interchannel inhibition with respect to processing of information. Specifically, intrachannel inhibition and intrachannel integration may have an effect such that the system must process the information for each component in each channel via a_{21} and a_{12} in order for processing to be completed. This would lead to either a positive or negative perceptual dependence. Moreover, intrachannel integration would not occur at the input or output stages and thus would not affect b_{21} and b_{12} or c_{21} and c_{12}. Therefore, each stimulus component (A, B), would at least partially affect the other processing channel, and hence a perceptual dependence would occur.

For a noise mask, Ashby (1989) assumed that the noise added to the different components by a noise mask would be dispersed over the input lines and to the processing channels, and that the noise is statistically independent. Thus, a noise mask should not affect perceptual separability, perceptual independence, or decisional separability. Therefore, the noise added by the noise mask should not affect the qualitative behaviour of the model (Ashby, 1989, p. 445). Instead, the effect of any interchannel or intrachannel inhibition, or intrachannel integration would be an increase in task difficulty and therefore a decrease in accuracy.

In the present experiment, the degree of interaction that occurs will be examined as a function of SOA and type of mask. On the basis of the prediction that a Type A masking function will occur for both types of masks, accuracy should show an overall increase as SOA increases. For the no mask condition, based on previous research, perceptual separability and decisional separability should hold for both dimensions (Garner & Felfoldy, 1970; Kadlec & Hicks, 1998).

In contrast, for the structure mask at a short SOA, since the structure mask shares common elements with the stimulus, a moderate degree of interaction, of PS type or PI type or both, is predicted to occur (Breitmeyer & Ganz, 1976). Thus, interchannel inhibition may occur between the transient activity of the mask components and the sustained activity of the stimulus components, via b_{21} and b_{12}, which would lead to a failure of perceptual separability. Intrachannel inhibition as well as intrachannel integration may also occur between the sustained cells of the stimulus and structure mask, via a_{11} and a_{22}, and a_{12} and a_{21}, for each component. Both intrachannel inhibition and integration would lead to a decrease in accuracy and a failure of perceptual independence. Furthermore, because interchannel inhibition, intrachannel inhibition and intrachannel integration are perceptual phenomena, they should not affect decisional separability.

For the noise mask at a short SOA, since the noise mask does not share common elements with the stimulus, the mask will simply add more noise to the signal-to-noise ratio within the sustained cells of the stimulus, and thus only increase task difficulty and not affect perceptual separability, perceptual independence, or decisional separability. Thus, the effect of the noise mask in this condition should be a decrease in accuracy.

Finally, at a long SOA, for both the structure mask and noise mask, very little interaction should occur if any at all (Breitmeyer & Ganz, 1976). Thus, the perception of the stimulus should not be affected by either the structure or noise mask. Some interchannel inhibition, however, may occur between the transient cells of the structure mask or noise mask and the sustained cells of the stimulus in this SOA condition. This may cause a decrease in accuracy, but not affect perceptual separability, perceptual independence, or decisional separability.

Method

Participants

Five paid volunteers from the University of Victoria served as participants for the experiment. Each participant received $5 per hour plus a $10 bonus upon completion of all sessions. One of the five participants completed an extra set of sessions that were conducted to determine what type of masking function was obtained for the structure mask and noise mask conditions. These sessions were conducted after the completion of the first experiment. All participants ranged from 20-25 years of age and had 20/20 or corrected vision.

Apparatus

Stimuli were presented on a 17" Optiquest Viewsonic monitor driven by an IBM-compatible Pentium 200 MHz desktop computer. A program written in Turbo Pascal 6.0 was used to display the instructions, present the stimuli, and collect the response data. The refresh rate for the monitor was 17 ms and stimulus onset was synchronized with the raster scan for the experiment.

Stimuli

Target stimuli. The target stimuli are shown in Figure 5(a). These stimuli are modifications of Shepard's (1964) original stimuli. The stimuli were modified in order to avoid some of the potential confounds with Shepard's original stimuli (Kadlec & Hicks, 1998). Specifically, in the original stimuli, a change in the size of the circle changed both the length of the radial line and the curvature of the arcs. The stimuli used for this experiment have arcs of constant height and radial lines of constant length. The two arcs were constructed from circles with radii of 30 pixels (Level 1) and of 34 pixels (Level 2) and the two oriented lines have slopes of 50° (Level 1) and 60° (Level 2) from a horizontal plane. All stimuli, presented in the center of the monitor, were black lines on a white background with the luminance of the stimuli at approximately 6.15 foot-lamberts (fL) and the luminance of the background at approximately 18.12 fL.

Structure mask. The structure mask is shown in Figure 5(b). The structure mask was designed such that the length of the straight lines were equal to the length of the radial line in the target stimuli, and the two curved lines used in the structure mask were identical to the curved lines in the target stimuli. The structure mask consists of randomly oriented black lines, composed of 6 curved lines (three from each level of the arc curvature dimension) and 6 radial lines, on a white background with the luminance of the mask at approximately 6.15 fL. The structure mask was displayed in the same location as the target stimulus.

Noise mask. The noise mask is shown in Figure 5(c). The noise mask was designed such that the mask elements and contours shared no structural relationship to the stimuli contours. The noise mask consists of a random array of black dots on a white background with the luminance of the noise mask at approximately 6.15 fL. The noise mask was displayed in the same location as the target stimulus.

Procedure

Participants were tested individually for approximately one hour for 5 days. Two sessions were completed per day for a total of 10 sessions. At the beginning of each session, each participant was seated in a room, 1.25 m from the monitor with his or her head positioned in a head rest. On the first day, participants read the instructions presented on the monitor, which were summarized again by the experimenter at the end of the instruction session. The first four sessions were considered practice and the data from these sessions were not included in the analyses. At the end of the sessions, any participant that did not perform within the desired range (between 60-90% correct) was paid for his or her time, but was not included in the analysis. There was one participant that did not perform in the desired range, and thus, only four participants' data were used for the analyses.

In the test phase, participants' response data were recorded. Before the beginning of each test session, participants completed five practice blocks in order to familiarize them once again with the experiment. For each session, participants completed all five of the following conditions in a random order. Condition 1 consisted of testing without a mask, which was included as the control condition; condition 2 consisted of testing with the structure mask at a short SOA of 119 ms; condition 3 consisted of testing with the noise mask at an SOA of 119 ms; condition 4 consisted of testing with the structure mask at a long SOA of 221 ms; and finally, condition 5 consisted of testing with the noise mask at an SOA of 221 ms.

For the extra sessions that one participant completed in order to determine the masking function for each type of mask, there were four new conditions. Condition 6 consisted of testing with the structure mask at an SOA of 0 ms (target and mask presented simultaneously); condition 7 consisted of testing with the noise mask at an SOA of 0 ms; condition 8 consisted of testing with the structure mask at an SOA of 51 ms; and condition 9 consisted of testing with the noise mask at an SOA of 51 ms. Since the participant was well practiced, only one practice session was completed. The participant was tested for one hour per session, two times a day for a total of 8 test sessions. Similar to the first set of sessions, before the beginning of each test session, the participant completed five practice blocks. Again, within each session, the participant completed all four conditions in a random order.

Participants pressed the space bar to begin each trial at which point a fixation point, located at the center of the screen, was replaced by one of the four stimuli. The entire stimulus was presented foveally to one of the four quadrants (randomly to one of upper left, upper right, lower left, or lower right) for 51 ms at a visual angle of 1°. This was done so that participants were not able to compare the previous stimulus to the new stimulus, from one trial to the next, which could potentially occur if the stimuli were always presented in the same location. After the presentation of each stimulus, depending on the condition, a mask appeared in the same location as the stimulus for 51 ms. After the participant had made his or her response, the fixation point appeared once again in the center of the screen to indicate that the next trial was ready.

To make a response, participants pressed one of two keys that indicated the level of each dimension. The first dimension participants responded to was the curvature of the arc and the second dimension that participants responded to was the orientation of the radial line. For the curvature of the arc, participants were asked to respond whether the arc was smaller (Level 1) or larger (Level 2), and for the line orientation, participants were asked to respond whether the orientation of the line was 50° (Level 1) or 60° (Level 2). The correct responses for each level of each dimension are indicated in Figure 6. For example, the correct response for the larger arc and 50° line orientation would be "21", where '2' indicates the response for the larger arc, and '1' indicates the response for the line orientation of 50°.

For the test phase, the alternating block sequence, A-D-A-D-... was used in which block A contained all four stimuli and block D contained one of two-stimulus blocks X_1 (stimuli 11 and 21), X_2(stimuli 12 and 22), Y_1(stimuli 11 and 12), Y_2(stimuli 21 and 22), P (stimuli 11 and 22), or N (stimuli 12 and 21), in random order (Kadlec & Hicks, 1998). This particular block sequence was used in order to provide the best opportunity for invariance of perceptual space to hold (see Results and Discussion section for more details) (Kadlec & Hicks, 1998). At the beginning of each block of trials, the participants were informed as to which set of stimuli would be tested for the next block of trials. Specifically, if they were presented with block A, P, or N, they were told that they were to make two responses, one for arc curvature and one for line orientation. Moreover, if they were presented with block P or N, they were told that, for block P, the responses for both dimensions would always be the same (either "11" or "22") and for block N, the responses for both dimensions would always be the opposite (either "12" or "21"). If participants were presented with block X_1, X_2, Y_1, or Y_2, they were told to only make one response, since the stimuli would vary along only one dimension. At the end of each block, feedback was given (percent correct) for that particular block in order to motivate participants and maintain their attention throughout the experiment. On each day, participants completed approximately 120 blocks of test trials, with 12 trials per block in the A blocks and 24 trials in all other blocks. Participants therefore completed a total of 108 trials per stimulus for the A blocks. For the second set of sessions that were completed to determine the masking functions, the participant completed 96 blocks of test trials per day, for a total of 144 trials per stimulus for the A blocks. At the end of all sessions, all participants were paid and debriefed.

Data Analysis

In a complete identification task with a feature-complete factorial design of stimuli as used here and described above, when all levels of component A are combined with all levels of component B, the proportion of correct responses and each type of error are obtained for each stimulus. These data are summarized in a confusion matrix and then analyzed to infer which types of information are processed independently from other information. The analysis is done using Multidimensional Signal Detection Analysis (MSDA) (Kadlec, 1995; 1999) which is a software program that uses the proportions in the confusion matrix to compute a number of sensitivity parameters (d'), decision criteria, and response bias (βs) estimates required to test perceptual separability, perceptual independence, and decisional separability, as defined in the GRT (Ashby & Townsend, 1986).

The sensitivity parameters (d's) that are estimated are the marginal and conditional parameters. To test for perceptual separability and decisional separability, the marginal d's and βs are used, and to test for perceptual independence, the conditional d's and βs are used. For each confusion matrix (i.e., for each participant in each condition), four marginal d' estimates are computed which correspond to the distances between the means along the two stimulus dimensions. An example of these marginal d' estimates is illustrated in Figure 7.

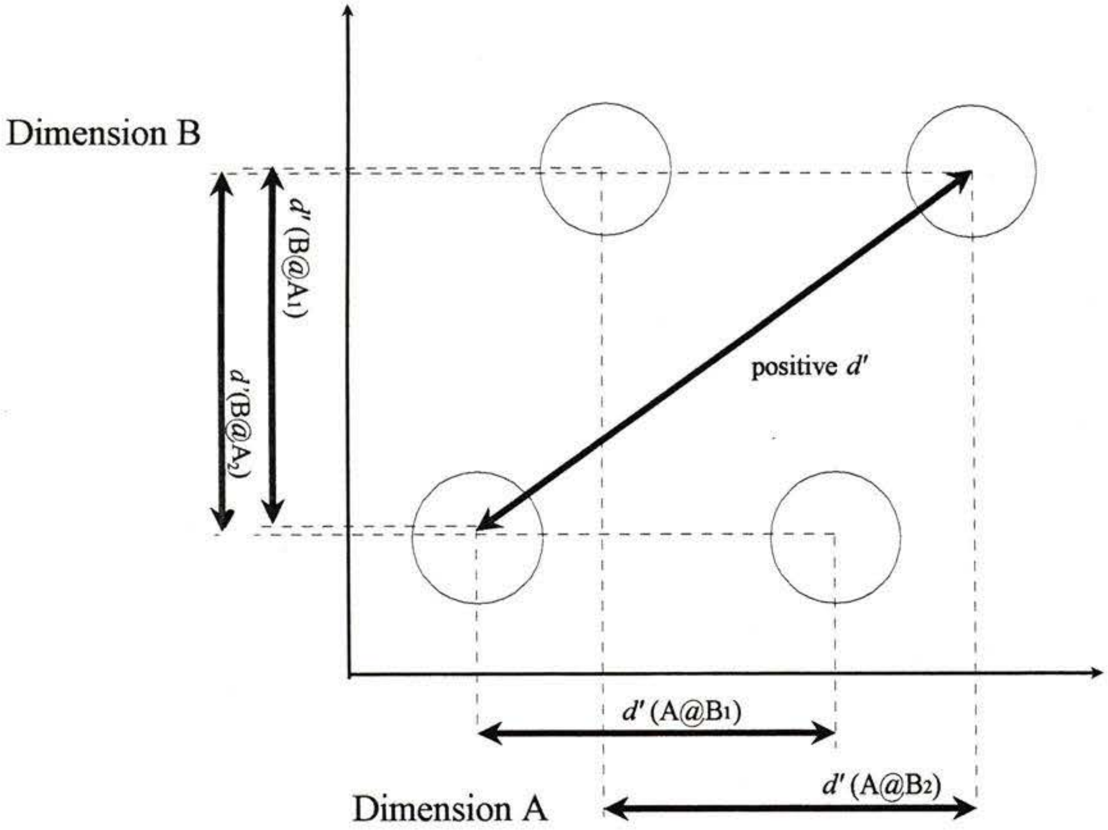


Figure 7. The marginal d' estimates that can be computed for each dimension across the levels of the other dimension.

For example, d' (A @ B_1) is the marginal d' estimate for Dimension A at the first level of Dimension B which represents the distance between stimulus A_1B_1 and stimulus A_2B_1 along the perceptual axis for Dimension A.

Testing for Perceptual Separability. Perceptual separability holds if and only if the perceptual effect of one feature does not depend on the level of the other. Kadlec and Townsend (1992b) showed that the necessary and sufficient conditions for two dimensions to be perceptually separable are: that the variances for each dimension are equal across the levels of the second dimension; that the marginal d's across the levels of the second dimension are equivalent; and, that the stimuli form a rectangular pattern in the perceptual space.

A two-step testing strategy is used in order to test whether or not the two dimensions being tested are perceptually separable. The first step is to test the marginal d's for equivalence. If the marginal d' values are not equivalent, then one concludes that perceptual separability has failed and no further analyses are required to test for perceptual separability. If the marginal d' values are equivalent, however, the second step is to test the rectangularity condition (see below). If rectangularity is supported, one concludes that perceptual separability holds for both dimensions. If rectangularity is not supported, one concludes that the pattern formed is a parallelogram (Kadlec & Hicks, 1998).

To test for rectangularity, an estimate of a diagonal d' is required. Either the positive d', between A_1B_1 and A_2B_2, or the negative d', between A_1B_2 and A_2B_1, can be used (Kadlec & Hicks, 1998). Rectangularity is then tested by using the Pythagorean Theorem which states that in a right-angle triangle, the squared hypotenuse equals the sum of the two sides squared. In order to test this, however, two conditions must first be met. First, one needs to assume that the variances of the d's are equivalent. Second, the test of rectangularity requires that perceptual independence holds in all stimuli and that all variances are equal within and across dimensions. Testing for perceptual independence can be done using the conditional d' estimates (see below). The equal-variance assumption, on the other hand, cannot be tested and therefore, an equal variance assumption underlies the results (Kadlec & Hicks, 1998). Perceptual separability was tested for the control condition (no mask) and all masking conditions.

Testing for Perceptual Independence. Perceptual independence holds if and only if the perceptual effects of the dimensions being tested are statistically independent (Ashby & Townsend, 1986). Perceptual independence can be tested using the conditional d' estimates and β estimates, and can be represented graphically. As previously mentioned, the equal likelihood contours for Gaussian densities whose components are independent are either circles, if the variances are equal, or ellipses with the major and minor axes parallel to the coordinate axes. If a correlation exists, the contours will be ellipses that are tilted either to the right, representing a positive correlation, or to the left, representing a negative correlation. To determine the configuration of the contours of stimuli in a given experiment or condition, the conditional d' estimates are used.

Based on the relative magnitudes of the conditional d' estimates, one can deduce whether dependencies exist, and if so, in what direction. For each dimension, four conditional d's are estimated, which are conditional on the participant's response to the other dimension. For the experiment with two dimensions being tested, there is a total of eight conditional d' estimates, or four pairs. Specifically, for each dimension, two pairs of conditional d' estimates were computed. For the first dimension, Arc Curvature, for stimuli A_1B_1 and A_2B_1, one conditional d' was computed given that the participant correctly responded that Line Orientation was at Level 1, and another d' was computed given that the participant incorrectly responded that Line Orientation was at Level 2. Similarly, for stimuli A_1B_2 and A_2B_2, one conditional d' for Arc Curvature was computed given that the participant incorrectly responded that Line Orientation was at Level 1 and another given that the participant correctly responded that Line Orientation was at Level 2. For the second dimension, Line Orientation, for stimuli A_1B_1 and A_1B_2, one conditional d' was computed given that the participant correctly responded that Arc Curvature was at Level 1, and another d' was computed given that the participant incorrectly responded that Arc Curvature was at Level 2. Similarly, for stimuli A_2B_1 and A_2B_2, one conditional d' for Line Orientation was computed given that the participant incorrectly responded that Arc Curvature was at Level 1 and another given that the participant correctly responded that Arc Curvature was at Level 2.

The configurations are determined by the values for each pair of the conditional d's. If two conditional d' estimates are equal, the densities for the corresponding pair of stimuli will have the same shape and will both be either circular or elliptical with the tilt in the same direction. If, however, the conditional d' estimates are not equal, the shapes can be determined by using their relative magnitudes. For example, in stimuli A_1B_1 and A_2B_1, if the d' estimate for the lower portion of the densities of Dimension A, when the participant responds that Dimension B was at Level 1 (i.e. below the Dimension B decision bound), is larger than the upper portion of the densities of Dimension A, then the two densities, A_1B_1 and A_2B_1, could be drawn as one of three possibilities as shown in Figure 8: (a) either A_1B_1 is perceptually independent and A_2B_1 shows a negative dependence; (b) A_1B_1 shows a positive dependence with perceptual independence in A_2B_1; or, (c) A_1B_1 shows a positive dependence and A_2B_1 shows a negative dependence. Figure 8 illustrates the three different configurations that could be used for this example.

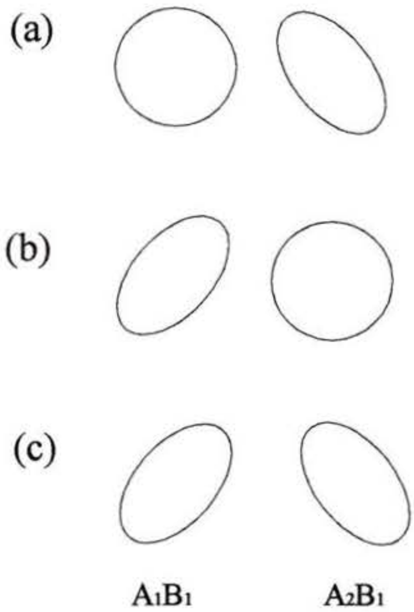


Figure 8. Three configuration possibilities when the conditional d' estimate for the lower portion of the densities of Dimension A is larger than the upper portion of the densities of Dimension A. (a) A_1B_1 is perceptually independent with A_2B_1 showing a negative dependence; (b) A_1B_1 shows a positive dependence with perceptual independence in A_2B_1; (c) A_1B_1 shows a positive dependence and A_2B_1 shows a negative dependence.

After determining all possible patterns of contours, an overall configuration is determined by eliminating those that are not possible based on the conditional d' estimates. On occasion, ambiguities arise when more than one possible set of contours are possible. For these cases, the pattern chosen will be based on parsimony, that is, the one that includes as many possible stimuli that are perceptually independent. Perceptual independence was tested for the control condition and all masking conditions.

Testing for Decisional Separability. Decisional separability holds if and only if the decision about one feature does not depend on the level of the other (Ashby & Townsend, 1986). Decisional separability can be tested by examining the decision bounds. If the decision bounds are parallel to the coordinate axes, then decisional separability holds for each of the stimulus features. The decision bounds are drawn by using the decision criterion values obtained from the data. For each dimension, one value is computed for each level of the other dimension. The values are then plotted for one dimension across the levels of the other dimension, and a line is drawn to connect the two values, which creates the decision bounds. Decisional separability was tested for the control condition and all masking conditions, but is not of primary interest here.

Results and Discussion

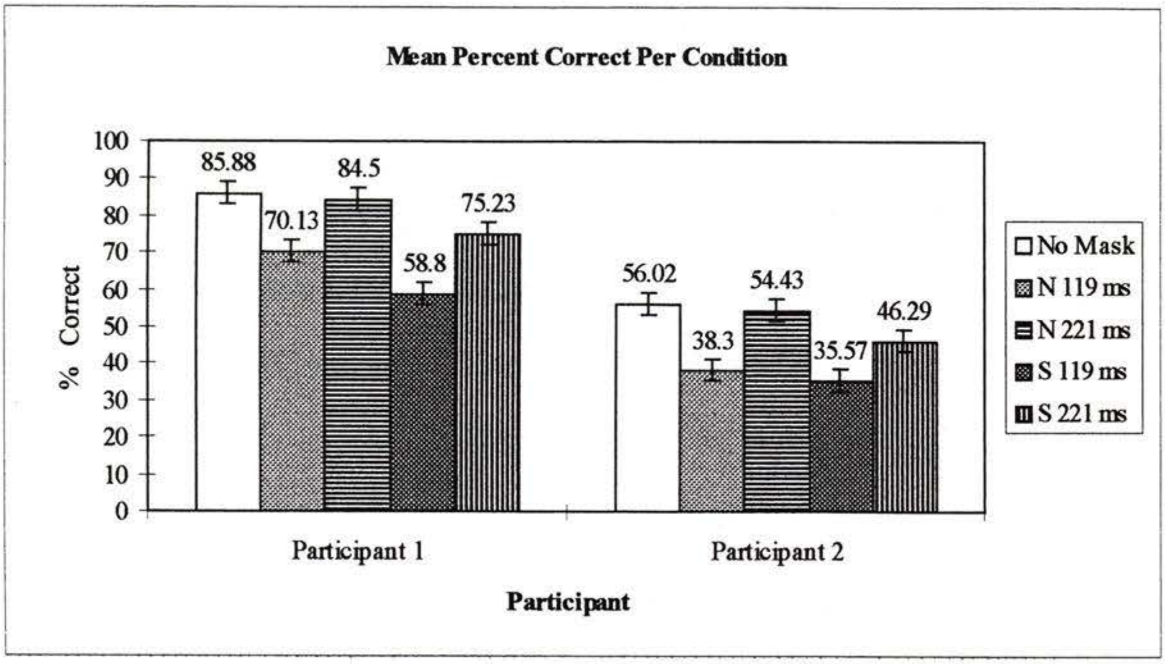
The following results are divided into three sections. The first section examines the classical masking effects with respect to the magnitude of the masking effect for the five different conditions. The second section examines the results of the second set of sessions, which were conducted to determine what type of masking function was obtained for the structure mask and noise mask conditions. The third section, which is of most interest, is further divided into three sets, one that examines perceptual separability, another that examines perceptual independence, and one that examines decisional separability for the five masking conditions.

For all of the analyses, the following conventions were followed. First, all analyses used the raw data from the A blocks, when all four stimuli were presented, unless stated otherwise. Any blocks of trials that were below chance (chance is 25% in this case) were not used in the analyses. Second, since all five conditions were completed for each session over a period of three test days, in order to collapse the data, I first ensured that there were no learning effects over the three days. In other words, I tested whether the mean accuracy data for all three test days for each participant were equivalent in order to collapse the confusion data into one matrix for each condition. During each test session, participants completed 12 blocks of trials and for each block, the percent correct was recorded. The mean accuracy data for each day were then computed using the percent correct from the blocks of trials. Thus, there were three means computed for each participant for each condition, one for each day.

To test for equivalence across the three test days, one t test was conducted for each of the four participants for each of the five masking conditions, for a total of 20 t tests. The error rate per comparison was set at $\alpha = .05$, in order to reduce the probability of a Type 2 error. The two means for each condition that were compared were the highest mean and lowest mean from the three days. No significant day differences were found ($p > .07$), therefore, all data for the following results were collapsed over the three testing days.

Classical Masking Effects

The mean accuracy data for all five conditions for each participant are shown in Figure 9. For each mean, one standard error of the mean is also shown to allow comparisons among conditions (Howell, 1992). For each participant, six t tests were conducted to compare the mean accuracy rates. Specifically, the no mask condition was compared individually to all other masking conditions, and the two structure mask conditions were compared as were the two noise mask conditions. To keep familywise error rate below $\alpha = .05$, the error rate per comparison for each t test was set at $\alpha = .008$.



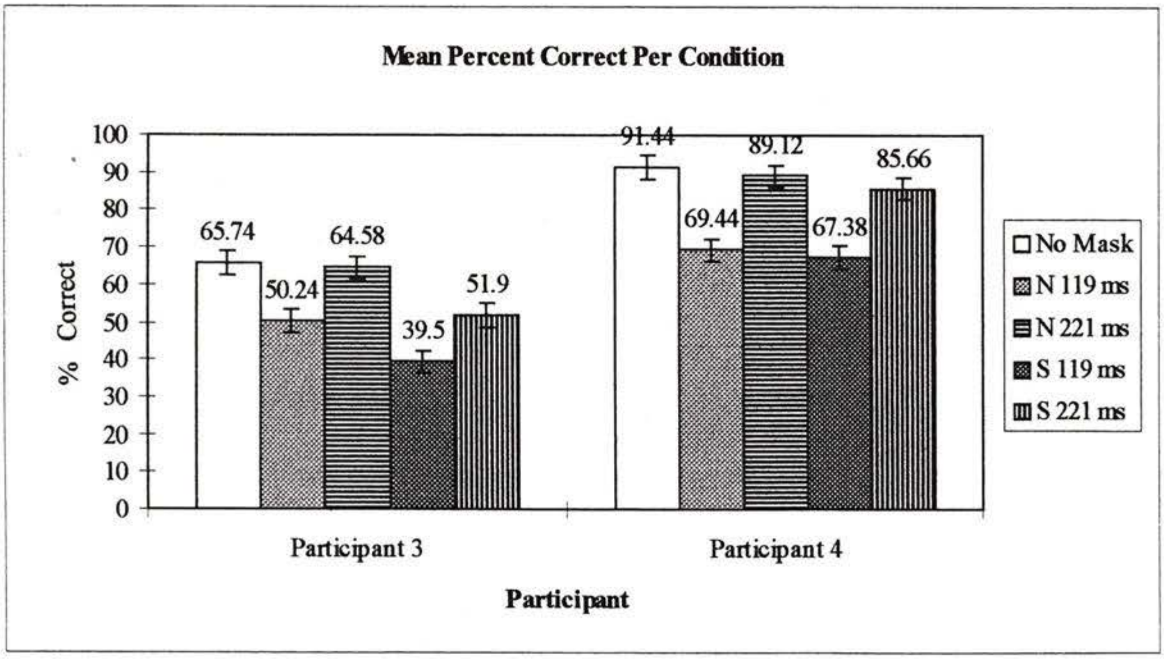


Figure 9. Mean accuracy data for all four participants for each of the conditions.

As predicted, the mean percent correct when no mask was presented was significantly greater than both 119 ms SOA structure mask and noise mask conditions for all four participants ($p < .001$). This result suggests that a mask, whether a noise mask or structure mask, makes the identification task more difficult when presented 119 ms after the onset of the presentation of the target item. For all four participants, the structure mask at an SOA of 221 ms made the identification task significantly more difficult than when no mask was presented ($p < .008$). In contrast, for all four participants, when the noise mask was presented at an SOA of 221 ms, no significant differences were found ($p >. 25$), although the no mask condition means were consistently larger. This result is not surprising when one considers previous research that has demonstrated that the more similar a mask's features are to the target features, the worse performance will be (Hellige, Walsh, Lawrence, & Prasse, 1979).

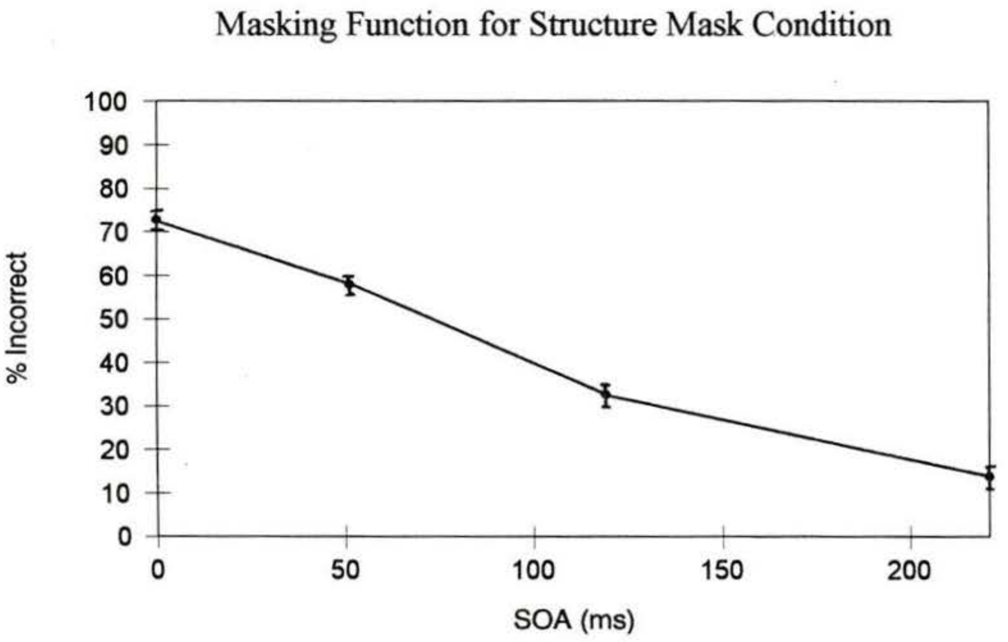
Of most interest, for all four participants the mean percent correct for the 119 ms SOA noise mask condition was significantly smaller than the 221 ms SOA noise mask condition ($p < .001$), and the mean percent correct for the 119 ms SOA structure mask condition was significantly smaller than the 221 ms SOA structure mask condition ($p < .001$). As expected, these results suggest that as SOA decreases error rate increases. Overall, the no mask condition produced the highest percent correct when compared to all other masking conditions, though not significantly different than the 221 ms SOA noise mask condition. In sum, the magnitude of the masking effect was greatest when the masks were presented 119 ms after the presentation of the target item, and was significantly reduced when the masks were presented 221 ms after the presentation of the target item.

The next section examines what type of masking function was obtained for the noise mask condition and structure mask condition.

Masking Function

The mean error data for the four SOA conditions for both the structure and noise masks, that were conducted to determine the masking function, are shown in Figure 10. Again, for each mean, one standard error of the mean is also shown. For both mask conditions, three t tests were conducted; one that compared the 0 ms SOA condition to the 51 ms SOA condition; one that compared the 51 ms SOA condition to the 119 ms SOA condition; and, one that compared the 119 ms SOA condition to the 221 ms SOA condition, for a total of six t tests. The error rate per comparison for each t test was therefore set at $\alpha = .0083$.

(a)


Masking Function for Structure Mask Condition

(b)

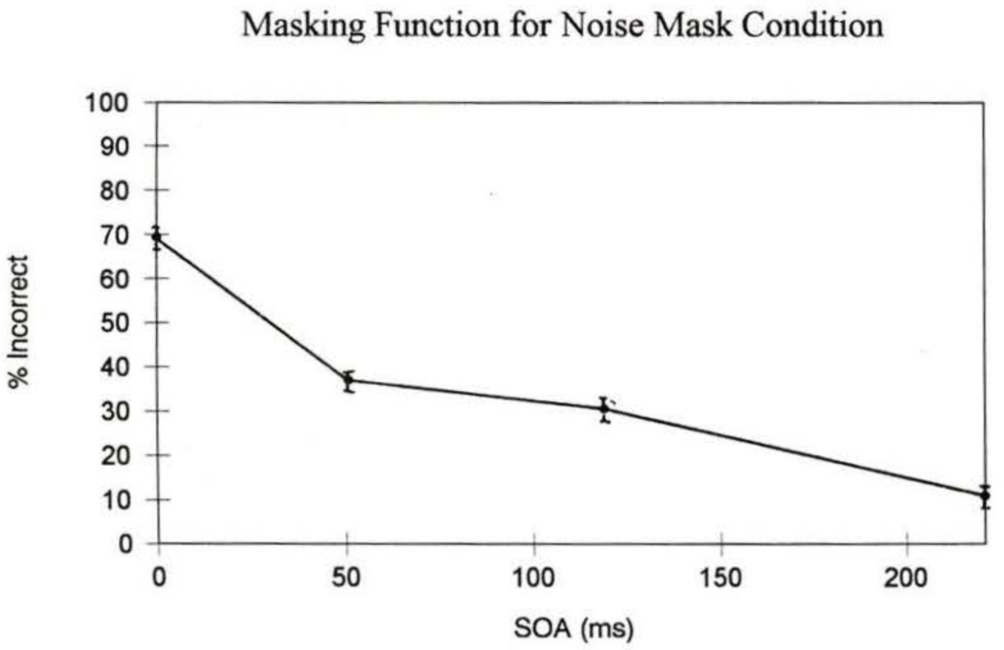

Masking Function for Noise Mask Condition

Figure 10. Masking function obtained for (a) structure mask, and (b) noise mask.

As predicted, for both the noise mask condition and the structure mask condition, Type A masking functions were obtained. For both mask conditions, error rate was greatest at an SOA of 0 ms, and significantly decreased as SOA increased ($p < .001$). The only non-significant difference in mean error rate was between the noise mask condition at an SOA of 50 ms compared to the noise mask condition at an SOA of 119 ms ($p = .027$). The real question of interest now is whether perception of the target item was affected by the presentation of the two masks, and if so, how.

Assessing Dimensional Interactions

For this next section, four sets of results will be discussed for each participant for each condition. First, the stimulus configurations are discussed at a general level. Then, the obtained marginal d' and diagonal d' estimates, which were used to infer whether perceptual separability held in all five conditions, are discussed in terms of dimensional interactions. These results were also dependent on whether perceptual independence held for all stimuli, therefore, an analysis of perceptual independence is discussed in the third set of results. Finally, the fourth set discusses the results in terms of decisional separability.

Stimulus Configurations. Figures 11, 12, 13 and 14 illustrate the stimulus configurations for participants 1, 2, 3, and 4, respectively. The top configuration for each figure represents the results from the no mask condition. The two configurations below the no mask condition are the two noise mask conditions and the bottom two configurations are the two structure mask conditions. Each axis represents perceptual effects for each dimension, which are measured in d' units. The solid points in the center of each circle or ellipse are the marginal d' estimates that were obtained from the A blocks (when all four stimuli are presented). Each center point is estimated by the marginal d's in relation to Stimulus A_1B_1, which is arbitrarily placed at the origin. The circles and ellipses represent the results of the perceptual independence analyses, which are discussed later. Finally, the lines represent the decision bounds, one for each dimension across the levels of the other dimension.

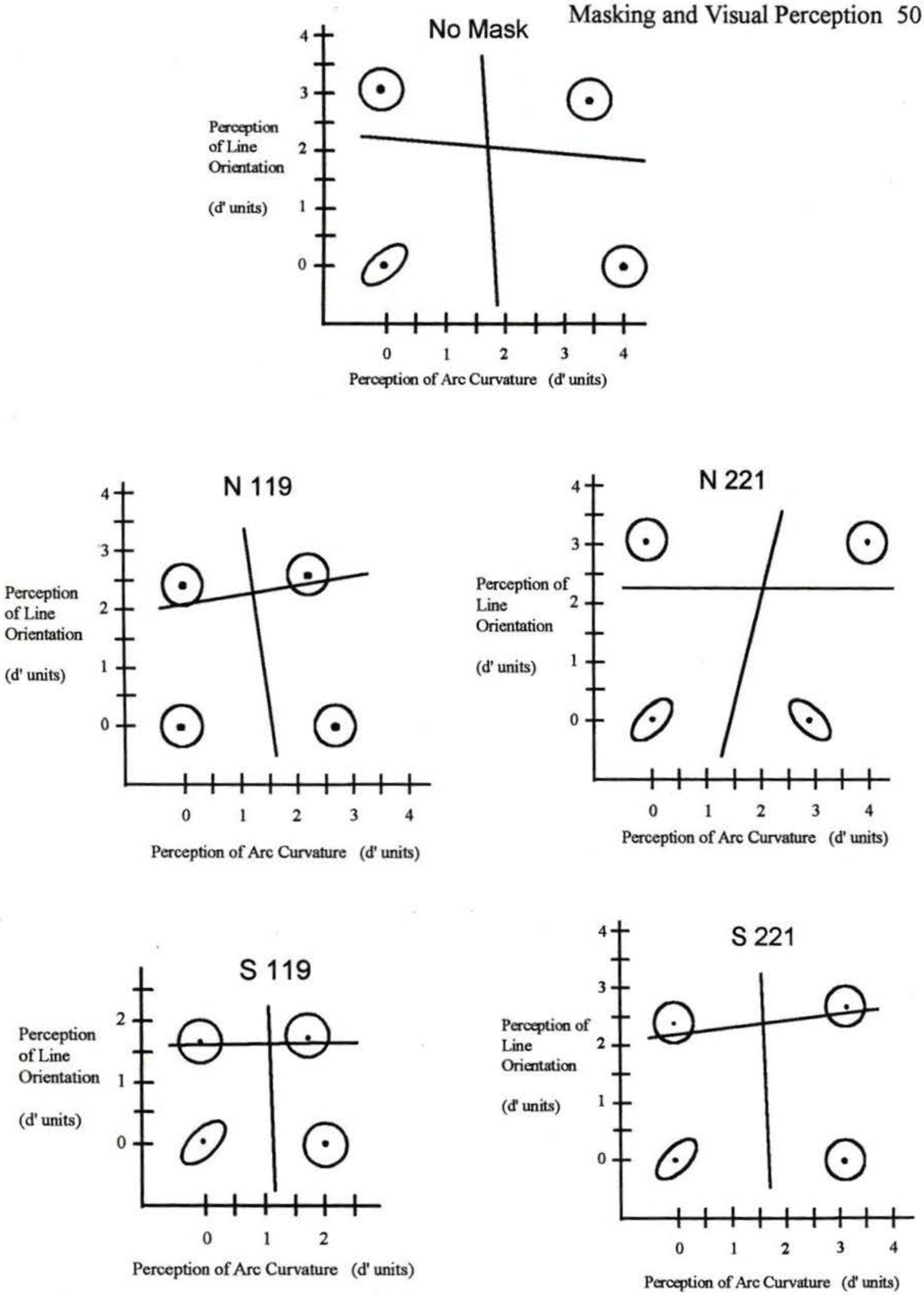


Figure 11. Estimated perceptual space for participant 1 for all five conditions.

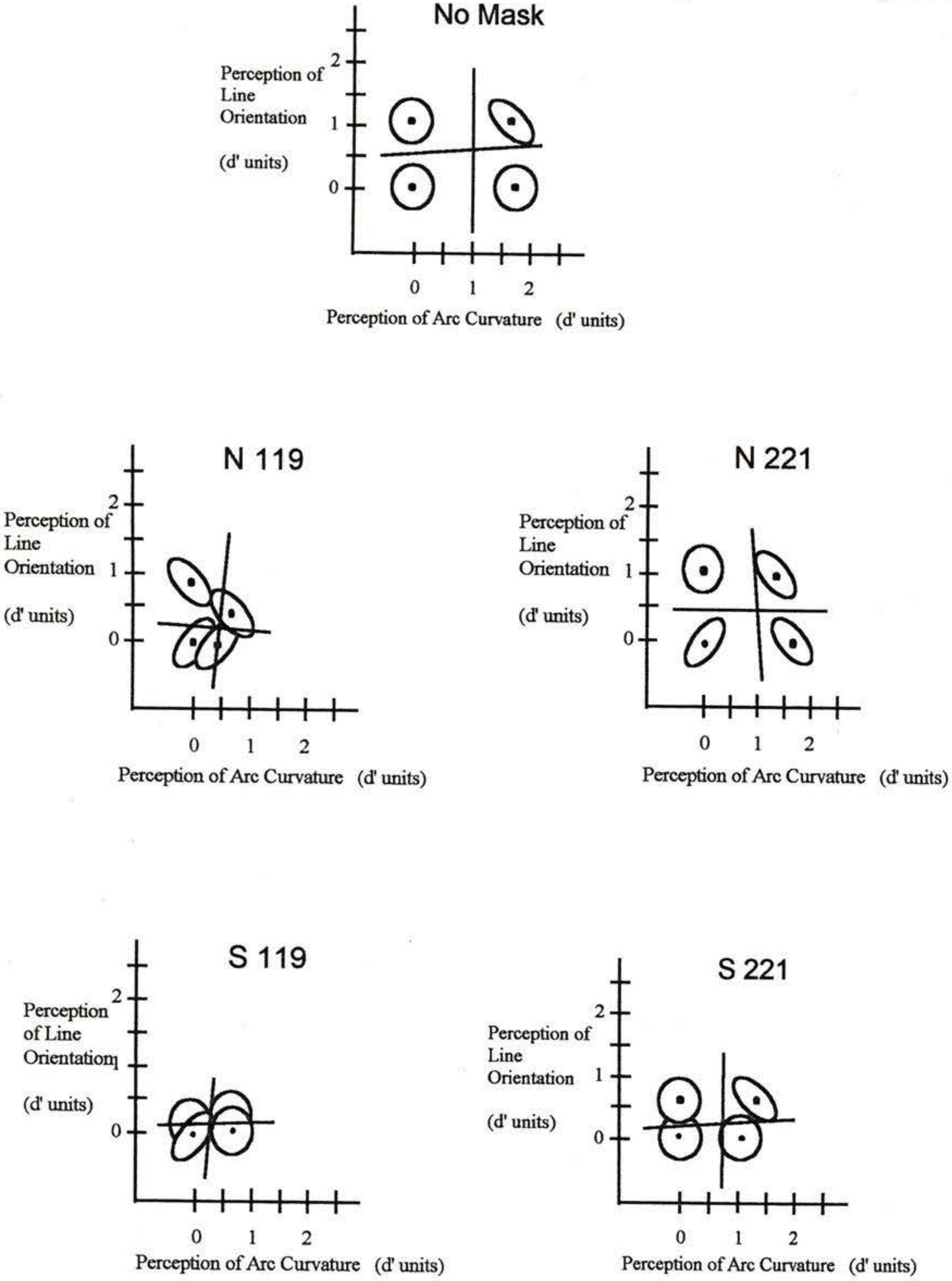


Figure 12. Estimated perceptual space for participant 2 for all five conditions.

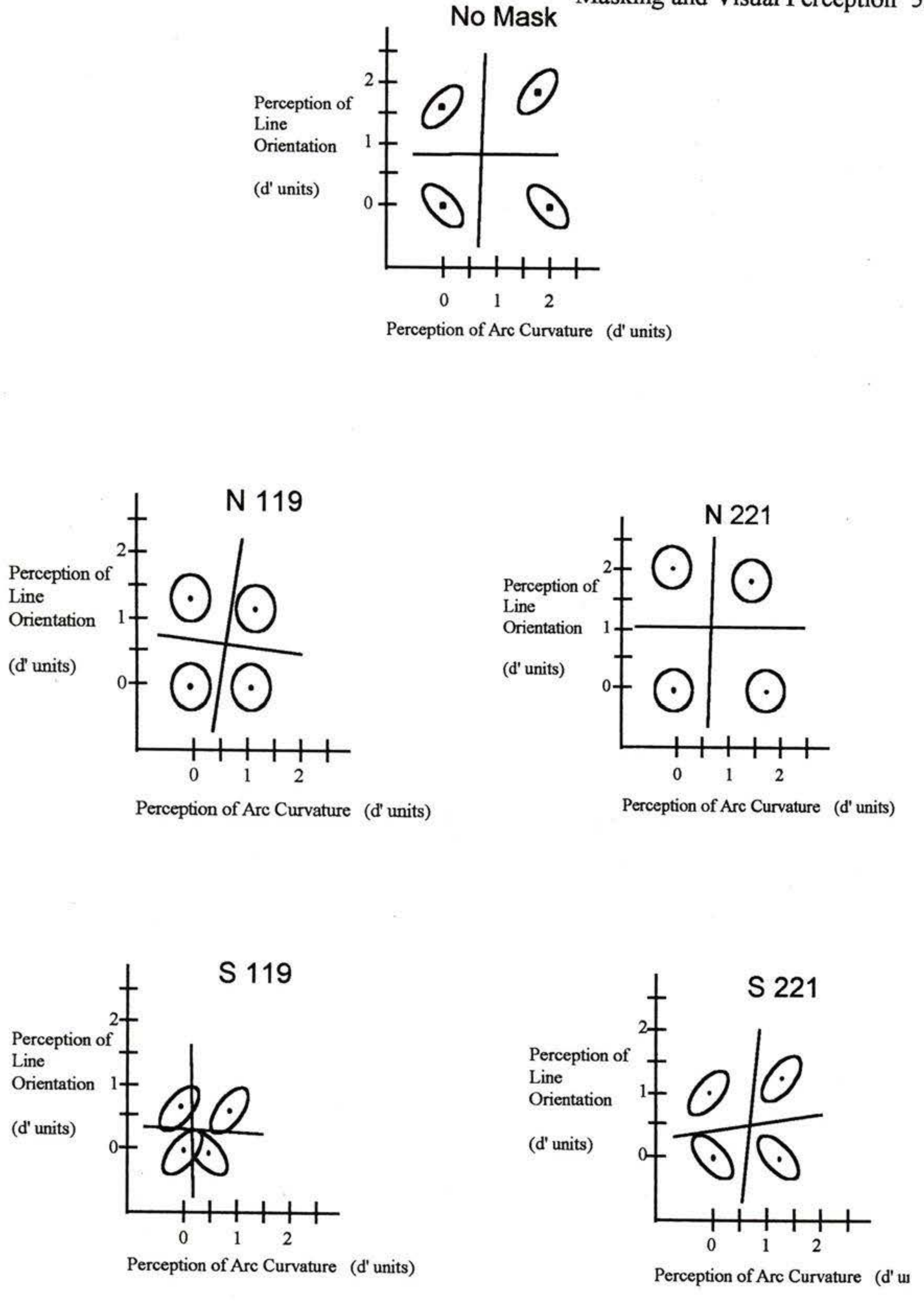


Figure 13. Estimated perceptual space for participant 3 for all five conditions.

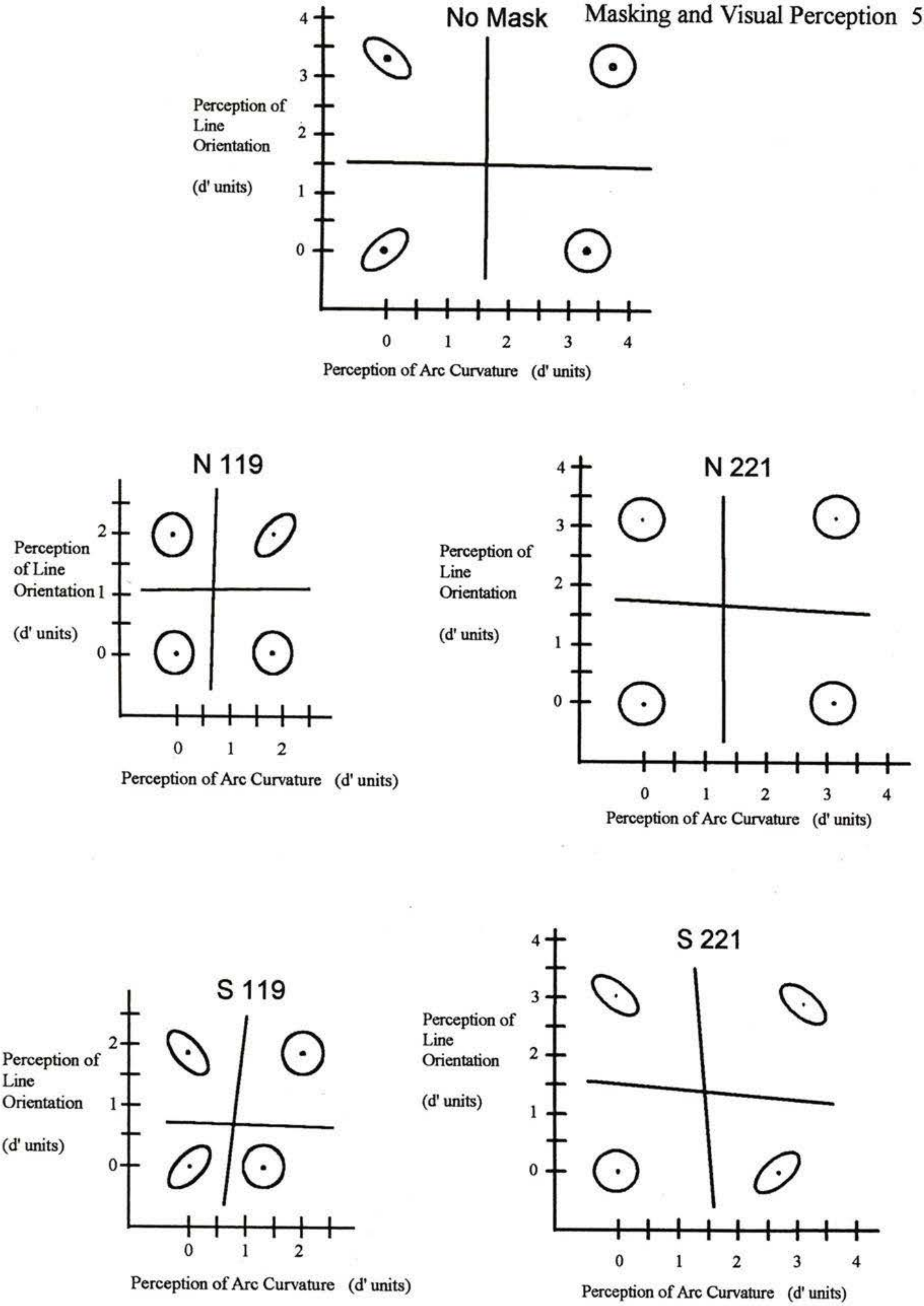


Figure 14. Estimated perceptual space for participant 4 for all five conditions.

The configurations are drawn by using the four marginal *d'* estimates for each condition in the following manner. First, the mean for stimulus A_1B_1 is placed at the origin since one stimulus must be arbitrarily set somewhere. The mean vector for stimulus A_2B_1 has an x-coordinate equal to *d'*(A @ B_1) because it lies *d'*(A @ B_1) units along the x-axis from stimulus A_1B_1, and the y-coordinate is zero. Similarly, for stimulus A_1B_2, it is placed at [*d'*(B @ A_1), 0] since it lies *d'*(B @ A_1) units along the y-axis from stimulus A_1B_1, and the x-coordinate is zero. Finally, the mean vector for stimulus A_2B_2 is placed at [*d'*(A @ B_2), *d'*(B @ A_2)] because it lies *d'*(A @ B_2) units along the x-axis from stimulus A_1B_2, and *d'*(B @ A_2) units along the y-axis from stimulus A_2B_1 (Kadlec & Hicks, 1998).

Before the results for perceptual separability, perceptual independence, and decisional separability are discussed, some general findings of the marginal *d'*s should be mentioned. First, note that for each condition for each participant, the marginal *d's* for each dimension are relatively equivalent to the marginal *d'*s for the other dimension. This indicates that Arc Curvature and Line Orientation were similar in level of difficulty for the identification task, and further, that the presentation of the noise mask and the structure mask did not affect this result. Second, as expected, the estimates of the marginal *d'*s were reduced as SOA decreased, indicating that the masks, when presented at an SOA of 119 ms, made the identification task more difficult. Finally, note that for participants 1 and 4, their marginal *d'* estimates in the no mask condition were much larger than the marginal *d'*s in the no mask condition for the other two participants. This result was due to the fact that both participants 1 and 4 had participated in two other similar experiments (both used the same stimuli and masks), thus, both participants were well practiced.

Perceptual Separability. Recall that Kadlec and Townsend (1992b) showed that the necessary and sufficient conditions for two dimensions to be perceptually separable are: that the variances for each dimension are equal across the levels of the second dimension; that the marginal d's across the levels of the second dimension are equivalent; and, that the stimuli form a rectangular pattern in the perceptual space. The first step is to test whether the marginal d's are equivalent. Table 2 provides the marginal d' estimates for all participants for all five conditions.

Table 2

Marginal d' estimates obtained for all participants for each condition

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Participant 1 **Marginal d's**	Arc Curvature @ level 1 of Line Orientation	Arc Curvature @ level 2 of Line Orientation	Line Orientation @ level 1 of Arc Curvature	Line Orientation @ level 2 of Arc Curvature
Mask and SOA Condition				
No Mask	4.000	3.468	3.151	2.776
Noise Mask @ 119 ms	2.679	2.256	2.491	2.695
Noise Mask @ 221 ms	2.976	4.037	3.151	3.120
Structure Mask @ 119 ms	2.082	1.735	1.589	1.740
Structure Mask @ 221 ms	3.169	3.275	2.491	2.719

Table 2 Continued

Participant 2 **Marginal d's**	Arc Curvature @ level 1 of Line Orientation	Arc Curvature @ level 2 of Line Orientation	Line Orientation @ level 1 of Arc Curvature	Line Orientation @ level 2 of Arc Curvature
Mask and SOA Condition				
No Mask	1.680	1.606	1.157	1.190
Noise Mask @ 119 ms	.387	.754	.877	.466
Noise Mask @ 221 ms	1.610	1.429	1.110	1.039
Structure Mask @ 119 ms	.621	.625	.097	.356
Structure Mask @ 221 ms	1.084	1.397	.594	.686

Participant 3 **Marginal d's**	Arc Curvature @ level 1 of Line Orientation	Arc Curvature @ level 2 of Line Orientation	Line Orientation @ level 1 of Arc Curvature	Line Orientation @ level 2 of Arc Curvature
Mask and SOA Condition				
No Mask	2.078	1.732	1.625	1.938
Noise Mask @ 119 ms	1.044	1.173	1.331	1.128
Noise Mask @ 221 ms	1.690	1.305	2.050	1.841
Structure Mask @ 119 ms	.438	.855	.597	.501
Structure Mask @ 221 ms	1.223	1.302	.955	1.305

Table 2 Continued

Participant 4 **Marginal d's**	Arc Curvature @ level 1 of Line Orientation	Arc Curvature @ level 2 of Line Orientation	Line Orientation @ level 1 of Arc Curvature	Line Orientation @ level 2 of Arc Curvature
Mask and SOA Condition				
No Mask	3.468	3.701	3.430	3.232
Noise Mask @ 119 ms	1.848	1.975	1.990	1.955
Noise Mask @ 221 ms	3.169	3.239	3.232	3.379
Structure Mask @ 119 ms	1.370	2.137	1.856	1.875
Structure Mask @ 221 ms	2.644	3.232	3.031	2.864

** d' s significantly different at the .05 level (2-tailed).
* d's significantly different at the .10 level (2-tailed).

Note.

Comparisons were made between the values for Arc Curvature at the different levels of Line Orientation, and between the values for Line Orientation at the different levels of Arc Curvature.

From the MSDA analyses, for all participants in all conditions, the marginal d' estimates for each dimension were equivalent across the two levels of the second dimension ($p > .10$). Note that the marginal d' estimates were only compared within each condition for each participant, not across conditions. For example, in the no mask condition, participant 1's marginal *d’* estimates for Arc Curvature were 4.00 at level 1 of Line Orientation and 3.47 at level 2 of Line Orientation. The results from the MSDA analyses indicate that these *d’* estimates for participant 1 were not significantly different ($p = .68$). Thus, one can conclude from these analyses that the configurations were either a rectangle or a parallelogram. The next step, therefore, is to test the rectangularity condition.

If the stimuli form a rectangular configuration, then the estimate for the positive diagonal *d’* will be equivalent to the estimate for the negative diagonal *d’* (Kadlec & Hicks, 1998). These two estimates were taken from the confusion matrix in the P blocks (where only stimulus A_1B_1 and A_2B_2 were presented) and N blocks (where only stimulus A_1B_2 and A_2B_1 were presented). The diagonal *d’* estimates for all conditions for all participants are presented in Table 3. Also included in Table 3 are the computed diagonal *d’* estimates which were obtained from the A blocks (see below).

Table 3

Positive and negative diagonal d' estimates obtained from the P and N blocks, respectively, for all participants for each condition. Computed diagonal d' estimates from the A blocks are also included

Participant 1	Direct Estimate for Positive d'	Upper ▲	Low ▲	Direct Estimate for Negative d'	Upper ▲	Low ▲
Mask and SOA Condition						
No Mask	4.915	4.686	4.868	3.787	4.442	5.092
Noise Mask @ 119 ms	3.289	3.361	3.8[illegible]	2.637	3.515	3.658
Noise Mask @ 221 ms	5.392	5.121	4.312	4.395	5.102	4.334
Structure Mask @ 119 ms	4.161	2.353	2.713	2.613	2.457	2.619
Structure Mask @ 221 ms	4.293	4.115	4.176	4.293	4.257	4.031

Table 3 Continued

Participant 2	Direct Estimate for Positive d'	Upper ▲	Low ▲	Direct Estimate for Negative d'	Upper ▲	Low ▲
Mask and SOA Condition						
No Mask	2.249	1.979	2.059	1.036	1.999	2.040
Noise Mask @ 119 ms	1.526	1.157	.606	1.759	.886	.959
Noise Mask @ 221 ms	2.032	1.809	1.916	1.733	1.767	1.956
Structure Mask @ 119 ms	.528	.632	.716	1.036	.719	.629
Structure Mask @ 221 ms	1.526	1.518	1.283	1.759	1.556	1.236

Participant 3	Direct Estimate for Positive d'	Upper ▲	Low ▲	Direct Estimate for Negative d'	Upper ▲	Low ▲
Mask and SOA Condition						
No Mask	2.213	2.375	2.841	2.108	2.599	2.638
Noise Mask @ 119 ms	1.463	1.774	1.537	1.263	1.627	1.692
Noise Mask @ 221 ms	1.482 *	2.43	2.499	3.118 *	2.257	2.657
Structure Mask @ 119 ms	.297	1.043	.665	.750	.991	.740
Structure Mask @ 221 ms	1.054	1.615	1.789	1.755	1.843	1.552

Table 3 Continued

Participant 4	Direct Estimate for Positive d'	Upper ▲	Low ▲	Direct Estimate for Negative d'	Upper ▲	Low ▲
Mask and SOA Condition						
No Mask	4.368	5.046	4.741	4.108	4.914	4.878
Noise Mask @ 119 ms	3.015	2.804	2.69	2.074	2.779	2.716
Noise Mask @ 221 ms	3.681	4.576	4.633	3.210	4.681	4.526
Structure Mask @ 119 ms	2.878	2.83	2.322	1.829	2.843	2.307
Structure Mask @ 221 ms	3.925	4.431	3.898	4.580	4.318	4.022

** d' s significantly different at the .001 level (2-tailed).
* d's significantly different at the .0025 level (2-tailed).

Note.

Comparisons were made between the direct estimates for the positive and negative d' values.

In order to examine whether a pair of diagonal d' estimates were equivalent, a statistical procedure suggested by Marascuilo (1970) was used. The null hypothesis, that $d'_1 = d'_2$ was tested using a z test, where $z = (d'_1 - d'_2) / \sqrt{[var(d'_1) + var(d'_2)]}$. Var(d') in this case is the variance of the d' estimate given by

$$\mathrm{var}(\underline{d'}) = \frac{\underline{\Pr(fa)[1 - \Pr(fa)]}}{N_n f^2(c)} + \frac{\underline{\Pr(hit)[1 - \Pr(hit)]}}{N_s f^2(c - \underline{d'})}$$

where Pr(fa) is the probability of a false alarm and Pr(hit) is the probability of a hit on which the d' estimate is based; N_n is the number of trials of the "noise alone" stimulus presentations, and N_s is the number of trials in the "signal + noise" stimulus presentations; f is the standard normal density; and finally, c is the decision criterion. The diagonal d' estimates for each participant for each condition were compared assuming that perceptual independence held in all stimuli, though this assumption is addressed next.

For each participant, five t tests were conducted to compare the diagonal d' estimates, one for each condition, for a total of 20 t tests. To keep familywise error rate below $\alpha = .05$, error rate per comparison was set at $\alpha = .0025$, thus, from the analyses, any z score greater than 2.81 indicated a significant difference between the two diagonal estimates being compared. From the analyses, only one diagonal estimate comparison was significantly different. For participant 3, the significant difference in the diagonal estimates occurred in the 221 ms SOA noise mask condition. Thus, for this one condition for this participant, one might conclude that the configuration formed a parallelogram. Invariance of perceptual space (Kadlec & Hicks, 1998), however, may not have held for this participant in this particular condition between the P, N, and A blocks. Invariance of perceptual space refers to the condition in which perception is not affected by the number or identity of the other stimuli in the ensemble. If invariance of perceptual space holds, the d' estimates will be equivalent (Kadlec & Hicks, 1998). Specifically, in this case, if the diagonal *d'* estimates from the P and N blocks are equivalent to the diagonal *d'* estimates from the A blocks, then one can conclude that invariance of perceptual space holds (see below how they are computed from the A blocks). Kadlec and Hicks (1998) demonstrated that, using the expanded experimental design used for this experiment, invariance of perceptual space held, but on a rare occasion, a failure of this assumption occurred. This may have occurred with participant 3. To test this, the diagonal *d'* estimates were computed from the A blocks and compared to the estimates obtained from the P and N blocks.

One can compute the positive diagonal *d'* estimates from the obtained marginal *d'* estimates using the Pythagorean relation $d'(\text{pos})_l = \sqrt{[d'^2(A @ B_1) + d'^2(B @ A_2)]}$ if one follows the route along the base of the rectangle and up the right-hand side (labeled lower route - subscript "l"), or $d'(\text{pos})_u = \sqrt{[d'^2(B @ A_1) + d'^2(A @ B_2)]}$ if one uses the route across the top of the rectangle and down the left-hand side (labeled upper route - subscript "u") (Kadlec & Hicks, 1998). One can analogously compute the negative *d'* estimates. These estimates are also included in Table 2 as "upper triangle" and "lower triangle" for each diagonal. If one takes the average of the two computed estimates for each diagonal for participant 3, comparisons can be made. One can clearly see that the two averaged diagonal *d'* estimates from the A blocks are equal. Specifically, the average of the positive diagonal *d'* estimates was 2.47 and the average of the negative diagonal *d'* estimates was 2.46. These estimates are equivalent, which indicates that the configuration formed a rectangle. Furthermore, when one compares the computed estimates from the A blocks to the obtained estimates from the P and N blocks, one can see that these are not equivalent

(2.47 and 2.46 compared to 1.48 and 3.12 for the positive and negative diagonal d' estimates, respectively). Therefore, invariance of perceptual space did not hold for this participant in this condition. Thus, on the basis of the comparisons made from the A blocks, the shape of the configuration is in fact a rectangle, and hence, for the 221 ms SOA noise mask condition for participant 3, one can conclude that perceptual separability holds for both dimensions.

The results just discussed indicate that the stimuli formed a rectangular configuration for all conditions for all participants, which would occur if perceptual separability held for both dimensions. The results for the no mask condition are not surprising, since previous research has demonstrated that these two dimensions are processed separably from one another (Garner & Felfoldy, 1970; Kadlec & Hicks, 1998). The diagonal d's, however, were computed and estimated under the assumptions that all the variances were equal and that perceptual independence held for all stimuli in all five conditions. If these assumptions hold, then the results would support the interpretation that perceptual separability holds for each of the two dimensions.

An overall examination of the configurations for all participants indicate that in some of the conditions, perceptual independence held in all four stimuli. In these cases, one can conclude that since perceptual independence held in the stimuli along the diagonals, the variances along those diagonals are equal, and therefore, perceptual separability holds for both dimensions. In some of the conditions, however, perceptual independence did not hold for all stimuli (see below for a more detailed analysis of perceptual independence). This result suggests that the assumption of equal variances along the diagonal d' estimates for these conditions may have been violated. A closer analysis of the patterns of dependencies along the diagonals, however, suggests that the variances may be equal nonetheless. Specifically, if both of the diagonal d' estimates are affected equally, then the conclusion for the test of perceptual separability is not affected. For example, in the 221 ms SOA noise mask condition for participant 1, there was a positive dependence in stimulus A_1B_1 and a negative dependence in stimulus A_2B_1 (see below). The positive dependence in stimulus A_1B_1 and the negative dependence in stimulus A_2B_1 suggests an increased variance in both diagonal estimates, but both were affected equally. Furthermore, the diagonal d' estimates computed from the A blocks for this particular participant in this condition provide further support that perceptual separability held for both dimensions since these two averaged estimates are equivalent. Therefore, since the diagonal d' estimates were not significantly different for participant 1 in the 221 ms SOA condition ($p > .10$), one can conclude that perceptual separability held for the 221 ms SOA noise mask condition for participant 1. A similar argument can be made for all participants in all conditions such that when perceptual independence failed in one or more of the stimuli along the diagonals, if the variances were equally affected, then conclusions about perceptual separability do not change. A general conclusion can therefore be made that perceptual separability held for both dimensions for all participants in all conditions, and thus, neither the noise mask or structure mask altered the perception of the stimuli in terms of perceptual separability. The next set of results examines perceptual independence, and specific details are discussed for each participant for each condition.

Perceptual Independence. In order to test for perceptual independence, one can use the MSDA methodology (Kadlec, 1995; 1999). The equal variances assumption unfortunately cannot be tested in the present version, therefore, equal variances are assumed for the following results. Recall that the shape of the joint distributions, or contours, indicate whether a correlation exists within a stimulus. The MSDA program does not compute parameter estimates for the correlation coefficients but does provide information that allows one to infer the direction of the dependencies when they exist. Specifically, a positive correlation is represented by an ellipse tilting to the right, and a negative correlation is represented by an ellipse tilting to the left. For both of these conditions, a failure of perceptual independence is inferred. When perceptual independence holds in a stimulus, the contour can be drawn as a either a circle or an ellipse parallel to either axis. Circles were drawn for perceptually independent stimuli to indicate equal variances.

Because of the complexity of the analyses, a detailed description for assessing the shapes of the contours will not be discussed. For a complete detailed description about graphically representing the equal probability contours in terms of perceptual independence, see Kadlec and Townsend (1992a, 1992b). The conclusions, for each participant for each condition, on the basis of the MSDA analyses of the conditional d's are represented graphically in Figures 11, 12, 13, and 14.

To begin, for participant 1, perceptual independence holds in the no mask condition for all stimuli except A_1B_1 (see Figure 11). The positive correlation found in stimulus A_1B_1 would in fact lead to a smaller positive diagonal d' than was actually estimated under the assumption that perceptual independence held in all stimuli. Furthermore, since all variances are assumed to be equal at the marginal level along both one-dimensional axes, the positive dependence found in stimulus A_1B_1 would lead to a larger variance along the positive diagonal direction and hence a smaller positive diagonal d'. The positive diagonal d' estimate, however, was not significantly different than the negative d' estimate ($p > .10$), indicating that the perceptual dependence was relatively small. Thus, on the basis of these results for participant 1 in the no mask condition, one can conclude that perceptual separability held, as did perceptual independence, with a small positive dependence in stimulus A_1B_1. This small positive dependence indicates that, for participant 1, when the 50° line was incorrectly reported as the 60° line, the arc tended to appear larger.

In the 119 ms SOA noise mask condition for participant 1, all four stimuli are perceptually independent. In comparison to participant 1's no mask condition, stimulus A_1B_1 is no longer positively correlated. This indicates that the presentation of the noise mask altered the dependency in the stimulus configuration. The change in the perception of the one stimulus suggests that the noise mask presented at this particular SOA altered perception in terms of perceptual independence, although this change is only slight.

In contrast, in the 221 ms SOA noise mask condition for participant 1, the same positive dependency held for stimulus A_1B_1, but a new dependency emerged. Specifically, stimulus A_2B_1, which was perceptually independent in the no mask condition, had a negative correlation in this condition. This negative correlation in stimulus A_2B_1 indicates that, for participant 1, when the 50° line was incorrectly reported as the 60° line, the arc tended to appear smaller. The emergence of a new dependence suggests that a change in perception occurred, in terms of perceptual independence, when the noise mask was presented, but again this effect was only slight.

These results, that the noise mask at both SOAs changed the shapes of the contours in the configurations, were not expected. One original prediction was that a significant reduction of the marginal d' estimates would be the only result for the 119 ms SOA condition, with a small reduction in the 221 ms SOA condition. This result was obtained. Another prediction, with respect to the shapes of the contours, was that there would be no change in the qualitative behaviour such that the correlations in the stimuli would remain the same for both noise mask conditions when compared to the no mask condition. This was not obtained. Instead, perceptual independence was affected by the presentation of the noise mask. The general result, therefore, is that perceptual separability was not affected by the presentation of the noise mask, but perceptual independence was.

In contrast, the identical configurations, with respect to perceptual independence, resulted in both the 119 ms and 221 ms SOA structure mask conditions when compared to the no mask condition. Thus, for both structure mask conditions, perceptual independence held for most stimuli, with a small positive dependence in stimulus A_1B_1. This result, that perceptual independence was not affected in the 119 ms SOA structure mask condition, was also not expected. The original prediction was that the structure mask with an SOA of 119 ms would affect the configuration, but the structure mask with an SOA of 221 ms would not. Consistent with the predictions, however, a significant reduction in the d' estimates occurred in the 119 ms SOA condition with a slight reduction in the 221 ms SOA condition. The general result, therefore, is that the presentation of the structure mask did not affect perceptual separability or perceptual independence. Was this also the case for participant 2?

For participant 2, perceptual independence holds in the no mask condition for all stimuli except A_2B_2 (see Figure 12). First, the negative correlation found in stimulus A_2B_2 would lead to a smaller variance along the positive diagonal direction and a larger positive d' estimate than was estimated. The positive diagonal d' was in fact larger than the negative d', but not significantly so ($p > .10$), indicating that the perceptual dependence was relatively small. Thus, on the basis of these results, for participant 2 in the no mask condition one can conclude that perceptual separability held, as did perceptual independence, with a small negative dependence in stimulus A_2B_2. This small negative dependence indicates that, for participant 2, when the 60° line was incorrectly reported as the 50° line, the arc tended to appear smaller.

In the 119 ms SOA noise mask condition for participant 2, perceptual independence failed for all four stimuli. In comparison to participant 2's no mask condition, the configuration completely changed with respect to perceptual independence. The only consistency in this condition, compared to the no mask condition, was the negative dependence found in stimulus A_2B_2. The negative dependencies found in stimulus A_1B_2 and stimulus A_2B_2 indicate that for participant 2, when the 60° line was incorrectly reported as the 50° line, the arc tended to appear smaller. Furthermore, the positive dependencies found in stimulus A_1B_1 and stimulus A_2B_1 indicate that for participant 2, when the 50° line was incorrectly reported as the 60° line, the arc tended to appear larger. On the basis of these results, one can therefore conclude that the presentation of the noise mask affected perceptual independence but did not affect perceptual separability, since the variances along the diagonals were equally affected by the dependencies.

Similarly, in the 221 ms SOA noise mask condition for participant 2, the same negative dependency held for stimulus A_2B_2, but new dependencies emerged. Furthermore, a previous perceptual independence in the no mask condition in stimulus A_1B_2 reemerged. These results indicate that the presentation of the noise mask changed the stimulus configuration with respect to perceptual independence. Again, these results were not expected. Furthermore, these results are similar to participant 1's in that perceptual independence was affected by the presentation of the noise mask, but perceptual separability was not.

In contrast to the noise mask conditions for participant 2, the 119 ms SOA structure mask condition more closely resembled the stimulus configuration found in the no mask condition. The configuration was not identical, however, since perceptual independence held stimulus A_2B_2 in this condition, and a new dependence emerged in stimulus A_1B_1. Although the configuration for the 119 ms SOA structure mask condition was not identical to the configuration found in the no mask condition, the minor changes that did occur were not as drastic as the changes found in either of the noise mask conditions. Furthermore, the effect of the structure mask in this condition is difficult to assess since the <u>d'</u> estimates are so small and any minor changes that did occur to the stimulus configurations are more likely due to the participant performing close to chance in this condition.

Consistent with the results found for participant 1, in the 221 ms SOA structure mask condition, the configuration with respect to the shapes of the contours was identical to those in the no mask condition. This indicates that the presentation of a structure mask 221 ms after the onset of the target does not affect perception of the target item with respect to perceptual separability and perceptual independence. Were the same conclusions found for participant 3?

For participant 3 the stimulus configurations indicate that perceptual independence failed for all four stimuli in the no mask condition (see Figure 13). First, note the interesting pattern of dependencies in the stimuli. When the 50° line was presented, for both levels of Arc Curvature, there was a negative dependence. The negative dependencies indicate that when the 50° was incorrectly reported as the 60° line, the arc tended to appear smaller. When the 60° line was presented, however, there was a positive dependence across the levels of Arc Curvature. The positive dependencies indicate that when the 60° line was incorrectly reported as the 50° line, the arc tended to appear larger. When the noise mask at both SOAs was presented, however, this pattern of dependencies was eliminated, and in fact, perceptually independence held in all stimuli for both noise mask conditions. Therefore, similar to participants 1 and 2, the presentation of the noise mask for participant 3 changed the perception of the stimuli in terms of perceptual independence but not perceptual separability.

Consistent with participants 1 and 2, for participant 3, the presentation of the structure mask had very little effect on the perception of the stimuli. In the 119 ms SOA structure mask condition, a very similar configuration to the no mask condition resulted. Specifically, perceptual independence failed for all four stimuli and, moreover, three of the four dependencies were in the same direction in the 119 ms SOA structure mask condition as the no mask condition. The one inconsistent dependency was in stimulus A_1B_1. This change, however, was very minor in comparison to the drastic changes that occurred for both noise mask conditions. Thus, one can conclude that the structure mask, for the 119 ms SOA condition, had very little effect on the perception of the stimuli in terms of perceptual independence. A similar conclusion can be made for the 221 ms SOA structure mask condition for participant 3. Specifically, the same configuration as the no mask condition resulted. Therefore, the presentation of the structure mask had very little effect on the perception of the stimuli for participants 1, 2, and 3. These conclusions can also be made for participant 4.

For participant 4, in the no mask condition, two of the four stimuli showed a dependence in the stimulus dimensions (see Figure 14). Stimulus A_1B_1 showed a positive dependence, which indicates that when the 50° line was incorrectly reported as the 60° line, the arc tended to appear larger. In contrast, stimulus A_1B_2 showed a negative dependence, which indicates that when the 60° line was incorrectly reported as the 50° line, the arc tended to appear larger. The positive correlation found in stimulus A_1B_1 would in fact lead to a smaller positive diagonal d' than was actually estimated under the assumption that perceptual independence held in all stimuli. Furthermore, since all variances are assumed to be equal at the marginal level along both one-dimensional axes, the positive dependence found in stimulus A_1B_1 would lead to a larger variance along the positive diagonal direction and an underestimated positive d'. Analogously, the negative dependence found in stimulus A_1B_2 would lead to a smaller negative diagonal d' estimate because of the larger variance. Thus, on the basis of these results for participant 4, in the no mask condition, one can conclude that perceptual separability held since the variances along the diagonals were equally affected, as did perceptual independence in stimuli A_2B_1 and A_2B_2, with a positive dependence in stimulus A_1B_1 and a negative dependence in stimulus A_1B_2.

In the 119 ms SOA noise mask condition, consistent with the other three participants, the configuration changed with respect to perceptual independence. The two stimuli that showed dependencies in the no mask condition no longer showed dependencies in the 119 ms SOA noise mask condition. Instead, a positive dependence emerged in stimulus A_2B_2. Thus, for participant 4, the presentation of the noise mask in this condition affected the perception of the stimuli in terms of perceptual independence, but perceptual separability was not affected. Similarly, in the 221 ms SOA noise mask condition, the shapes of the contours in the configuration changed. Specifically, perceptual independence held in all four stimuli. Therefore, for participant 4, when the noise mask was presented, regardless of SOA, perceptual separability was not affected but perceptual independence was.

In the 119 ms SOA structure mask condition for participant 4, the identical configuration as the no mask condition resulted. Thus, for this condition, the presentation of the structure mask did not affect the perception of the stimuli in terms of perceptual separability and perceptual independence. An unexpected result occurred, however, in the 221 ms SOA structure mask condition. The configuration that resulted was quite different than the configuration for the no mask condition. A closer analysis of the data, however, revealed that when the stimulus configurations were drawn separately for each day for the 221 ms SOA structure mask condition, the configurations for two of the three days were identical to the configuration that resulted in the no mask condition. On one of the days, however, the configuration was quite different. Specifically, on day 3, the results of the analyses indicated that, on the basis of 36 trials per stimulus, perceptual independence held in all four stimuli. Thus, when the data were collapsed across the days, the resulting configuration was different. The finding that two of the three days resulted in the same configuration as the no mask condition suggests that there was a tendency for the configuration to be the same. One could therefore argue that the structure mask had little effect on the perception of the stimuli. In summary, one can conclude that the presentation of the structure mask had very little effect on the perception of the stimuli in terms of perceptual separability and perceptual independence for all four participants. In contrast, the presentation of the noise mask had moderate to extreme effects on the perception of the stimuli. The next set of results examines if decisional separability was affected by the presentation of the masks, and if so, how.

Decisional Separability. Recall that for decisional separability to hold for a given dimension, the decision bound, C_A, for Dimension A, for example, must be parallel to the Y axis (Ashby & Townsend, 1986). Using the data obtained from the A blocks, two points along each perceptual axis are computed and then compared for equivalence using the MSDA methodology (Kadlec, 1995; 1999). The two estimates for each participant for each condition are provided in Table 4. The two estimates are also used to indicate the placement and directions of the decision bounds which are illustrated, for each participant, in Figures 11, 12, 13, and 14.

Table 4

Criterion values obtained from A blocks for all participants for each condition

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Participant 1 **Criterion**	Arc Curvature @ level 1 of Line Orientation	Arc Curvature @ level 2 of Line Orientation	Line Orientation @ level 1 of Arc Curvature	Line Orientation @ level 2 of Arc Curvature
Mask and SOA Condition				
No Mask	1.915	1.682	2.355	1.915
Noise Mask @ 119 ms	1.593	1.128	2.085	2.602
Noise Mask @ 221 ms	1.383 *	2.355 *	2.355	2.355
Structure Mask @ 119 ms	1.221	1.173	1.682	1.786
Structure Mask @ 221 ms	3.169	3.275	2.491	2.719

Table 4 Continued

Participant 2 **Criterion**	Arc Curvature @ level 1 of Line Orientation	Arc Curvature @ level 2 of Line Orientation	Line Orientation @ level 1 of Arc Curvature	Line Orientation @ level 2 of Arc Curvature
Mask and SOA Condition				
No Mask	1.005	1.044	.482	.734
Noise Mask @ 119 ms	.431	.739	.247	.159
Noise Mask @ 221 ms	1.15	1.054	.402	.460
Structure Mask @ 119 ms	.260	.431	.097	.129
Structure Mask @ 221 ms	.704	.862	.163	.355

Participant 3 **Criterion**	Arc Curvature @ level 1 of Line Orientation	Arc Curvature @ level 2 of Line Orientation	Line Orientation @ level 1 of Arc Curvature	Line Orientation @ level 2 of Arc Curvature
Mask and SOA Condition				
No Mask	.562	.765	.796	.765
Noise Mask @ 119 ms	.482	1.173	.796	.482
Noise Mask @ 221 ms	.646	.796	1.005	1.044
Structure Mask @ 119 ms	.234	.171	.331	.203
Structure Mask @ 221 ms	.511	.949	.303	.682

Table 4 Continued

Participant 4 **Criterion**	Arc Curvature @ level 1 of Line Orientation	Arc Curvature @ level 2 of Line Orientation	Line Orientation @ level 1 of Arc Curvature	Line Orientation @ level 2 of Arc Curvature
Mask and SOA Condition				
No Mask	1.682	1.786	1.513	1.446
Noise Mask @ 119 ms	.674	.704	1.128	1.221
Noise Mask @ 221 ms	1.383	1.325	1.786	1.593
Structure Mask @ 119 ms	.594	1.111	.652	.566
Structure Mask @ 221 ms	1.516	1.446	1.516	1.271

** d' s significantly different at the .05 level (2-tailed).
* d's significantly different at the .10 level (2-tailed).

Note.

Comparisons were made between the values for Arc Curvature at the different levels of Line Orientation, and between the values for Line Orientation at the different levels of Arc Curvature.

The results from the analyses indicate that all decision bounds for both dimensions are parallel to the comparative axes, except for one. For participant 1, in the 221 ms SOA noise mask condition, decisional separability failed for Arc Curvature across the levels of Line Orientation ($p < .10$), although this failure is a relatively weak one and could in fact be a Type 1 error. The overall results suggest that, consistent with previous research

(Garner & Felfoldy, 1970; Kadlec & Hicks, 1998), decisional separability holds for both dimensions in the no mask condition, and further, that the presentation of a noise mask or a structure mask does not affect the perception of the stimuli with respect to the decisional process.

At this point, an overall summary of all of the results would be helpful. The first section of the results examined the classical masking effects. The magnitude of the masking effects were examined using the accuracy data from the A blocks (when all four stimuli were presented). The results suggest that as SOA increased, the magnitude of the masking effect decreased. Specifically, the mean accuracy rate for the no mask condition was significantly greater than the mean accuracy rate for the 119 ms SOA noise mask condition, and greater, but not significantly, than the 221 ms SOA noise mask condition. Similarly, the mean accuracy rate for the no mask condition was significantly greater than the mean accuracy rate for both structure mask conditions. Finally, as predicted, the mean accuracy rates for both the 221 ms SOA noise mask and structure mask conditions were significantly larger than the 119 ms SOA noise mask and structure mask conditions, respectively.

The second section of the results examined what type of masking function was obtained for both the noise mask and structure mask conditions. As predicted, for both masks a Type A function was obtained. Specifically, the largest error rate for both conditions occurred when the target item and mask were presented simultaneously, and moreover, as SOA increased, error rate decreased. The results of greatest interest, however, were the results of the dimensional interactions. First, consistent with previous research (Garner & Felfoldy, 1970; Kadlec & Hicks, 1998), in the no mask condition, perceptual separability and decisional separability held for both dimensions. Second, for all four participants, neither the structure mask or noise mask affected perceptual separability for any of the SOA conditions. Third, and this is a new result, perceptual independence was affected by the presentation of the noise mask for all four participants, with the effect ranging from moderate to extreme. In contrast, the presentation of the structure mask had relatively no effect on perceptual independence, though there was a very minor effect on perceptual independence in the 119 ms SOA structure mask condition for participants 2 and 3. Finally, decisional separability was not affected at all by the presentation of the noise mask or structure mask. The question that is addressed in the next section of this paper is why the noise mask had such an effect on the perception of the stimuli whereas the structure mask did not.

General Discussion

The primary question addressed in the present experiment was whether the presentation of a mask alters the perception of target stimuli. Researchers have typically used a visual mask to make the detection or identification process of a target item more difficult, but have not used the General Recognition Theory framework (Ashby & Townsend, 1986) to assess the effect of the presentation of a backward mask. The present experiment examined whether the presentation of a backward structure mask or a backward noise mask altered the perception of visual stimuli, and if so, how.

The perception of visual stimuli was assessed in terms of dimensional interactions using the GRT framework (Ashby & Townsend, 1986) to examine how stimulus dimensions affect each other during perceptual processing. Three general sets of results were discussed. The first set of results discussed the classical masking effects in terms of the magnitude of masking effect (measured by mean percent correct) as a function of SOA. The second set of results discussed the type of function that was obtained for the two types of masks, and the third set of results discussed dimensional interactions and compared the results of the dimensional interactions when no mask was presented to the results when either a noise mask was presented or a structure mask was presented. The following discussion will follow a similar format, but will combine the results of the classical masking effects with the results from the sessions that were conducted to determine the masking function for the two types of masks. The discussion concludes with a brief examination of two important empirical issues regarding the methodology used for this experiment; reliability and power. The general discussion begins with the classical masking effects.

Classical Masking Effects

The type of function that was obtained for both the structure and the noise mask was a Type A function. When the target and either type of mask were presented simultaneously, performance was at or near chance. The results indicate that as SOA increased, performance improved. These data support the classical masking data that demonstrate that when a Type A function is obtained, as SOA increases, error rate decreases and hence performance improves (Breitmeyer, 1984). Thus, as the time between the onset of the target and mask increases, target identification threshold decreases. Furthermore, the presentation of the structure mask made the identification task more difficult in comparison to when the noise mask was presented, as evidenced in the superior performance in all noise mask conditions. These results are also consistent with previous masking literature that has demonstrated that the more similar a mask is to the target item, the more difficult the task (Hellige et al., 1979). The next section discusses the results of the dimensional interactions, and explains the differences found between the effect of the presentation of the noise mask and the structure mask.

Dimensional Interactions

The primary question that the present experiment addressed was whether the presentation of a noise mask or a structure mask would alter perception of a target item in terms of dimensional interactions. The GRT framework (Ashby & Townsend, 1986) was used to assess what types of dimensional interactions occurred, and more specifically, was used to assess if perceptual separability, perceptual independence, or decisional separability were affected by the presentation of these two types of masks. Using the transient-sustained theory of visual masking (Breitmeyer & Ganz, 1976), predictions were made as to if and how perception may be affected by the presentation of a noise mask or structure mask within the GRT framework. In order to make these predictions, Ashby's (1989) dynamic version of the GRT was presented, which proposes that for each component of a stimulus, there is a processing channel, and further, that each processing channel for each component can mutually interact. The predictions were as follows.

For the no mask condition, based on previous research, it was predicted that perceptual separability would hold, as would decisional separability (Garner & Felfoldy, 1970; Kadlec & Hicks, 1998). For the 119 ms SOA structure mask condition, it was predicted that there would be a significant reduction of the d' estimates and that perceptual separability would fail, as would perceptual independence. In contrast, for the 119 ms SOA noise mask condition, it was predicted that since the noise mask does not share any common elements with the stimulus, the noise mask would not affect the qualitative behaviour of the model. Instead, only a reduction of the d' estimates would result. Finally, for both 221 ms SOA structure mask and noise mask conditions, it was predicted that very little interaction should occur at all, and thus neither perceptual separability, perceptual independence, or decisional separability would be affected. Instead, a slight reduction of the d' estimates would result.

Consistent with the predictions, in the no mask condition perceptual separability and decisional separability held for both dimensions for all participants, with individual differences in perceptual independence. Also consistent with the predictions, as SOA decreased, a reduction in the d' estimates occurred, which indicates that the presentation of the masks made the identification task more difficult as a function of decreasing SOA. Not consistent with the predictions, however, were the effects that the structure mask and the noise mask had on the perception of the target items in terms of the dimensional interactions. First, for all participants, perceptual separability and decisional separability was maintained for both dimensions in all masking conditions. This result, that perceptual separability held, was not expected for the 119 ms SOA structure mask condition. Also unexpected was the finding that the presentation of the structure mask at an SOA of 119 ms had very little effect, if any at all, on the shapes of the contours in the configurations. Specifically, for participants 1 and 4, the identical configuration in terms of perceptual independence emerged in the 119 ms SOA structure mask condition as the no mask condition, and for participants 2 and 3, a very similar configuration emerged in the 119 ms SOA structure mask condition as the no mask condition.

The slight difference between participants 1 and 4 and participants 2 and 3 could have resulted from the difference in the amount of practice that participants 1 and 4 had received. Specifically, both participants 1 and 4 had previously participated in two other similar experiments. The only difference between the previous experiments was that the same stimuli were white on a black background. This advantage in amount of practice was evidenced in the marginal d' estimates for participants 1 and 4 such that their estimates were considerably larger than the other two participants' marginal d' estimates. This difference is minimal, however, and does not affect the general finding that the presentation of the structure mask does not affect the perception of the stimuli.

Consistent with the predictions, in the 221 ms SOA structure mask condition, for all four participants, the structure mask did not affect perceptual separability, perceptual independence, or decisional separability. Also consistent with the predictions, for both noise mask conditions, perceptual separability and decisional separability were not affected by the presentation of the noise mask. The unexpected results, however, were the changes in the stimulus configurations in terms of perceptual independence when the noise mask was presented both 119 ms and 221 ms after the presentation of the target item. In order to explain why the structure mask had little or no effect on the perception of the stimuli and why the noise mask had a moderate to severe effect on the perception of the stimuli in terms of perceptual independence, a return to Ashby's (1989) stochastic model of dimensional processing will be useful.

Stochastic GRT

Since perceptual separability and decisional separability held for both dimensions in all masking conditions, the previous complex model presented in Figure 6 can be reduced to a more simple model. Figure 15 provides two processing models; one for the target and structure mask (15(a)); and, one for the target and noise mask (15(b)).

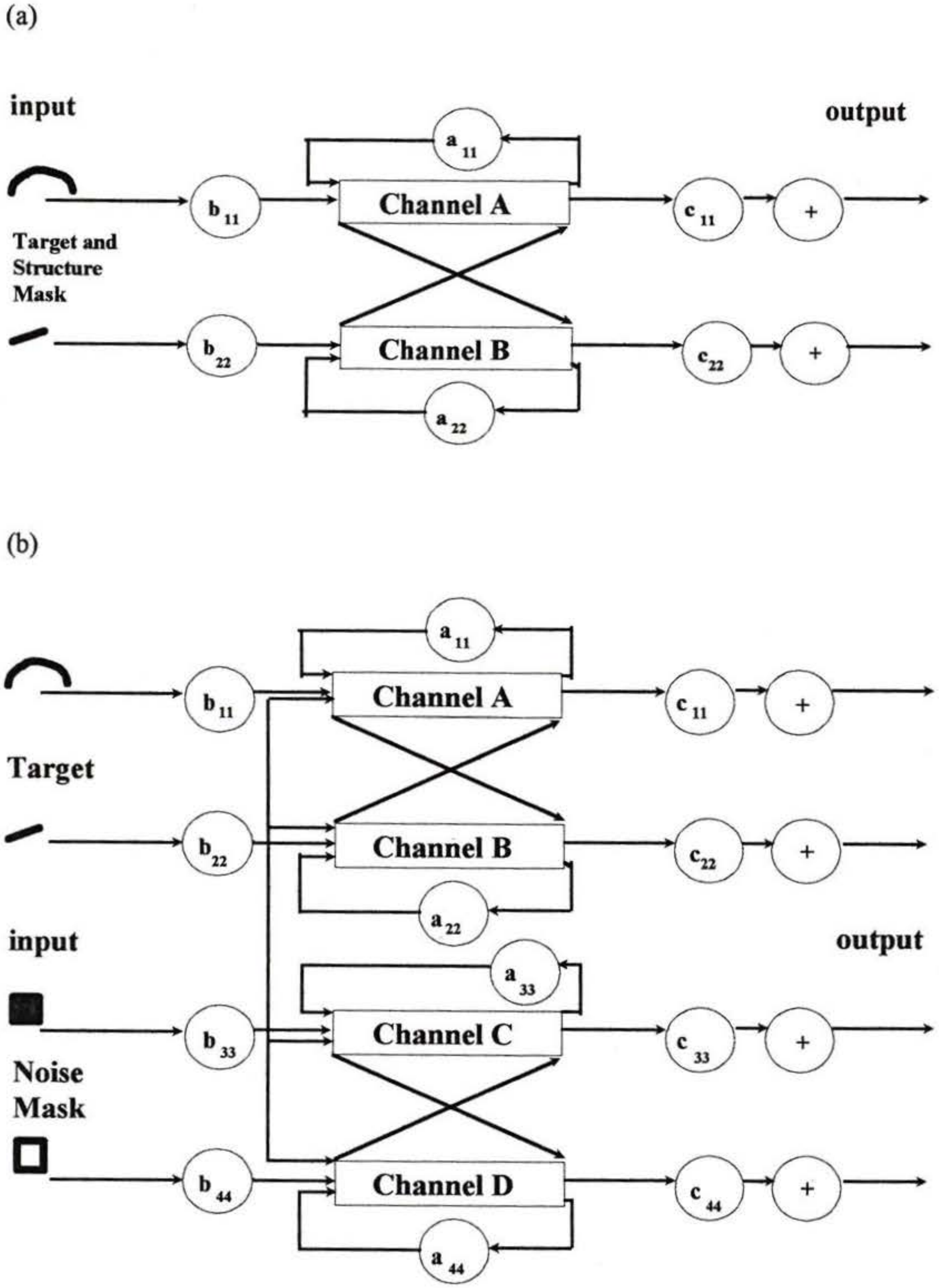

Figure 15. The connections between the hypothetical processing channels for target and both types of masks.

Figure 15(a) illustrates two processing channels, one for each component of the target and structure mask. The target and structure mask are both processed in the same two channels since they are composed of the same components. Specifically, both are composed of arcs and lines. Channel A, in this case, processes the arcs and channel B processes the lines. The distinction between the target and structure mask is temporal; the target is the input to channels A and B at time 1, and the structure mask is the input to channels A and B at time 2. Perceptual separability is indicated by no cross lines at the input stage ($b_{21} = b_{12} = 0$), potential failure of perceptual independence is indicated by the crosstalk lines at the channels ($a_{21} \neq 0$ and $a_{12} \neq 0$), and decisional separability is indicated by no cross lines at the output stage ($c_{21} = c_{12} = 0$).

Recall that Ashby (1989) proposed that for each component of a stimulus there is a processing channel and that all processing channels for a stimulus can mutually interact. When two stimuli, with two components each, are presented either simultaneously or within a short temporal interval and are composed of different components (such as the target and noise mask), four separate processing channels are activated, and can all mutually interact. Thus, for the present experiment, when the target and noise mask are presented, four separate processing channels are activated. Figure 15(b) illustrates these four processing channels. The two components of the target are processed in channels A and B, and the two components of the noise mask are processed in channels C and D. For the target, the two components are arcs, which are processed in Channel A, and lines, which are processed in Channel B. For the noise mask, the two components are black squares, which are processed in Channel C, and white squares, which are processed in

Channel D. Again, perceptual separability is indicated by no cross lines at the input stage, potential failure of perceptual independence is indicated by the crosstalk lines at the channels, and decisional separability is indicated by no cross lines at the output stage.

To explain the results obtained for the 119 ms and 221 ms SOA structure mask conditions, first consider that the target item and structure mask are composed of the same components, and thus, are processed in the same channels. When the structure mask is presented 119 ms after the presentation of the target item, target information processing is not complete, and hence, a large amount of interchannel and intrachannel inhibition occurs. This is evidenced in the increase in error rate and the decrease in the marginal d' estimates for all four participants in this condition. Since the target and mask share the same processing channels, however, more inhibition is occurring than would result when the noise mask is presented because the system is processing very similar information within the same channels. This similarity, however, does not affect the system in terms of the dimensional interactions as the system is only processing arcs and lines.

When the structure mask is presented 221 ms after the presentation of the target item, processing of target information is almost complete, hence very little interchannel and intrachannel inhibition is occurring. Since the information that is being processed is similar, and since information processing is almost complete, the system is not affected by the presentation of the structure mask in terms of the dimensional interactions. The task is still more difficult, however, than when no mask is presented, and is also slightly more difficult than when a noise mask is presented since the system is processing very similar information within the same processing channels.

Similar to the 119 ms SOA structure mask condition, when the noise mask is presented 119 ms after the presentation of the target item, a large amount of interchannel and intrachannel inhibition is occurring as evidenced in the increase in error rate and the decrease in the marginal d' estimates for all four participants. When the noise mask is presented 221 ms after the presentation of the target item, however, very little interchannel and intrachannel inhibition is occurring, again because target information processing is almost complete. When the noise mask is presented at either SOA, however, dimensional interactions are affected in terms of perceptual independence.

When the noise mask is presented, either 119 ms or 221 ms after the presentation of the target item, an attentional switch occurs such that the system is no longer processing information solely in the two channels. Instead, the system must either divide or shift attention over four processing channels. The attentional switch affects the system such that the system cannot reach a state of equilibrium for the processing of the target item, and hence perceptual independence is affected even when the system has almost completed processing of the target item.

How perceptual independence is specifically affected is in the following manner. Since the channels for both the target item and noise mask are connected, and can therefore mutually interact, information from one component can affect processing of another component via interchannel connections within the system. This would result in a failure of perceptual independence. If, however, the attentional switch affects the system such that information is prevented from passing between channels in the system, then perceptual independence would hold. For each participant, the effect of the presentation of the noise mask differs for each stimulus, as evidenced in the different dependencies in the stimuli. This should not be surprising, however, since the dependencies also vary from one stimulus to the next in the no mask condition.

In essence, the perceptual effect that results when a mask is presented is a combination of both the target and mask. Depending on the type of mask, there may no longer be a pure measure of perception for the target item alone. When a structure mask is presented, the perceptual effect of target + mask is equivalent to the perceptual effect of target alone, since the target and mask are composed of the same components. When a noise mask is presented, however, the perceptual effect of target + mask is no longer equivalent to target alone since the system is processing arcs, lines, white squares, and black squares. The perceptual effect when the noise mask is presented can therefore be explained as a perceptual effect of four dimensions instead of just two. The next section discusses reliability and power issues.

Empirical Issues

Two issues that arise that are of potential concern are the reliability of the data, and whether or not there is enough power to detect when two d' values are significantly different. The issue of reliability emerges when one examines the results of the dimensional interactions at the micro level. Specifically, there is considerable variation between participants when looking at the perceptual dependence of the stimuli. In the no mask condition, one might expect that the shapes of the configurations would be relatively similar for all participants. This, however, is not the case. The question then arises exactly how reliable are the data? Should one be concerned about individual differences?

Within the realm of statistics, reliability is defined as the degree to which a measure is consistent. To assess reliability in the present study, performance was examined across days. Specifically, the same pattern of results emerged with respect to the shapes of the contours for each test day for each participant. First, the results of the day data indicate that for all participants, at least 2 of the three days resulted in the same configuration as the one obtained when the data were collapsed. Often, the third configuration that did not fit the pattern was one in which the pattern of results could not be drawn. This can happen, on occasion, when the relationships between the conditional d's lead to inconsistent conclusions. For example, if all pairs of conditional d's are equivalent with the exception of one pair, there is no pattern of dependencies that could be drawn to illustrate that one inequality. In the present data, since the patterns of dependencies are consistent across days, one can conclude that the measures used are reliable.

Moreover, to test reliability at a more macro level, one can examine if the results from a prior pilot study are similar to the results found in this study such that the noise mask affected perception but the structure mask did not, in terms of perceptual independence, and that neither masks affected perceptual separability or decisional separability. Reliability at a more macro level is supported by the results of a pilot study that also indicate that neither perceptual separability or decisional separability were affected by the presentation of either types of masks. Although the pilot study had a significantly different procedure (white stimuli were presented on a black background and mask conditions were blocked by day), the interesting pattern was once again, how perceptual independence was affected. Specifically, for all three participants, the presentation of the structure mask had very little affect on the perception of the target item, whereas the noise mask did.

For one participant, however, the results were slightly different than the results for the other two participants. Specifically, for one participant, the presentation of the structure mask had more of an affect on perception in comparison to the other participants. The inconsistency with the third participant, however, could have resulted from a lack of motivation, concentration, or attention, which is supported by the significantly higher error rates for those conditions in comparison to the other participants’ error rates for those conditions. Therefore, since the data are reliable across days and across experiments, one can conclude that the measure is reliable, and thus, one should not be concerned about individual differences at the micro level.

The second issue is whether or not there is enough power to detect when two d’ values are significantly different. First, the large number of trials (approximately 108 per estimate) provide accurate probability estimates on which to base the marginal d’ estimates. Second, all hypotheses are tested at $\alpha = .10$, so power should be maximized. Third, when one examines the conditional d’ estimates (which are based on fewer trials than the marginal d’s), since significant differences were found, one can conclude that if the test is powerful enough to detect significant differences on the basis of a smaller number of trials at the conditional level, then there is enough power to detect significant differences at the marginal level. Hence, one could strongly argue that power is not an issue.

Summary

The question addressed in the present experiment was whether the perception of a visual stimulus would be altered by the presentation of either a backward structure mask or a backward noise mask, and if so, how the effect of these two types of masks may differ. The question was assessed using the GRT framework (Ashby & Townsend, 1986) to examine how stimulus dimensions interact during perceptual processing. The results of the experiment demonstrate that the presentation of either mask makes the target identification task more difficult, and specifically, as SOA increases, performance improves. The real question of interest was whether perceptual separability, perceptual independence, or decisional separability, as defined within the GRT framework, would be affected by the presentation of a structure mask or a noise mask. The results indicate that when either a structure mask or noise mask is presented after the presentation of a target item, neither perceptual separability or decisional separability are affected. Furthermore, the presentation of the structure mask has very little effect on perceptual independence. When the noise mask is presented, however, perceptual independence is greatly affected.

Therefore, if one is interested in examining the perception of visual stimuli and would like to use a mask to make the identification process more difficult, or any task in which perception is studied, a structure mask is the preferred mask to use if one wants to measure a more pure perception of the target item. One should not be fooled by the name "noise mask", as this experiment has demonstrated that a noise mask is much more than simply noise. It is a stimulus in its own right that obviously affects the perceptual process.

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Title of Thesis: Pattern Masking and Visual Perception: Assessing the Effects of a Structure and Noise Mask using the General Recognition Theory

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