Can a Long Term Perceptual Hypothesis Affect Visual Perception?

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Abstract

Visual masking is a psychophysical method commonly used to study visual information processing. Visual masking can be used to study the time course of visual information processing, but one of the limitations of this method is its inability to separate perceptual level processing from decision level processing. This study demonstrates that perceptual level processing can be separated from decision level processing by using a series of alternative forced choice visual masking tasks. Priming of perceptual level information is demonstrated. This priming can not be explained by existing feed forward visual information processing theories, but can be explained by the objects substitution model (Di Lollo et. al., 2000).

INTRODUCTION

The visual perception of a target object can be disrupted by the presentation of another object. This is a phenomenon known as visual masking. There are two major theoretical approaches used to explain visual masking. Traditional explanations are based on a feed forward approach to visual information processing (Breitmeyer, 1984; Kahneman, 1968; Turvey, 1973). The discovery of a new form of visual masking has lead to the development of a new theoretical approach based on feedback processing of visual information (Di Lollo, Enns, & Rensink, 2000). In Feed forward processing theories, the mechanisms of visual masking rest exclusively within the early stages of visual processing (Breitmeyer, 1984). Feed back processing theories describe a top down component of visual processing that can produce visual masking based on interaction between the object level representation of the target (i.e., the icon) and the object level representation of the mask (Di Lollo et al., 2000). When a feedback approach to visual information processing is adopted, a division between pre-iconic (i.e. early) processing and post-iconic (i.e. late) processing is no longer appropriate. A better division is between the processes that are involved in forming an object level visual representation about visual information and processes that occur after that visual representation has been formed.

Methods of Visual Masking

Visual masking is a common tool used to study visual information processing because of the diversity and sensitivity of its measures. Visual masking measures disruptions in visual information processing caused by specific changes in the experimental design. Information about the time course as well as the magnitude of disruptions of visual information processing can be collected during a visual masking experiment, and relatively small changes in the experimental design can have significant affects on these measures.

Most visual masking studies use a delayed onset paradigm. Individual trials begin with the display of one of one stimulus – either a target object or a mask object – for a brief period of time, usually somewhere between 10ms to 50ms. The first object is then turned off and the display remains blank for a varied period of time, after which the second object is displayed. Following Kahneman (1968), when the target stimulus is the first object in the display sequence, the resulting disruption of the visual perception of the target is referred to as backward masking. When the target is the second object in the display sequence, the resulting disruption of the visual perception of the target is referred to as forward masking.

The degree to which the visual representation of the target object is disrupted is referred to as the strength of the masking effect. The disruption of the visual perception of the target can be measured behaviorally using response accuracy scores on a variety of tasks. One common task is a target identification task. This task requires the participant to identify the form or contour of the target object (Bachmann, Luiga, & Põder, 2005; Kahn & Mathis, 2002). A common target identification task is to name a target letter or number (Enns, 2004). A target discrimination task is another common task. In a target discrimination task participants are asked to report a particular aspect of the target object such as its color (Breitmeyer, Öğmen, & Chen, 2004; Breitmeyer, Ro, Öğmen, & Todd, 2007) or brightness (Bernstein, et al., 1973; Proctor, Nunn, & Pallos, 1983).

The temporal component in a delayed onset masking paradigm usually refers to the stimulus onset asynchrony (SOA) between the target and the mask (Kahneman, 1968). Time course of disruptions in visual perception in a delayed onset masking paradigm can be measured by examining the strength of masking at the various time points (i.e. SOAs).The strength of masking in a delayed onset paradigm is affected by a wide range of experimental parameters such as the relative brightness of the stimuli (Fehrer & Smith, 1962), the degree of similarity between the contours of the masking object and the target object (Houlihan & Sekuler, 1968), and the requirements of the experimental task (Kahneman, 1968). There are four major categories of masking as defined by the relationship between the components of target and mask stimuli: masking by light, masking by noise, masking by structure and metacontrast masking.

Masking by light refers to a reduction in the ability to detect a target flash of light when it is masked by a second flash of light. In most masking by light studies the intensity of a making flash of light is held constant while the intensity of the target flash is systematically changed. The initial target flash is of low intensity and is gradually increased across successive trials until the observer is able to detect its presence. The strength of masking is measured by the level of intensity of the target flash that is required for the observer to detect its presence. The temporal pattern of masking by light generally shows strongest masking at or very near a 0ms SOA, with a gradual decline in masking with longer negative SOAs (i.e. forward masking) and little or no masking at positive SOAs (Crawford, 1943; Matsumura, 1976; Sperling, 1965). While central (i.e. cortical) processing cannot be ruled out as a mechanism for masking by light, the general findings implicate pre-cortical processing involving transient light and dark adaptation as the primary cause of this type of masking (Breitmeyer, 1984).

Masking by noise refers to masking caused by a masking object that is made up of a field of random visual information (such as a field of randomly placed dots) that spatially overlaps the target (Kinsbourn & Warrington, 1962). Masking by noise using a target discrimination task shows low accuracy scores at 0ms, as well as early positive and negative SOAs, with a fast rise in accuracy scores at later SOAs (Kinsbourn & Warrington, 1962).

Structure masking refers to masking caused by an object that is made up of features that are similar to those of the target, such as using an alphabetic letter that spatially overlaps with a target alphabetic letter (Brietmeyer & Ganz, 1976). Structure masking usually shows low accuracy scores at 0ms, and early positive and negative SOAs, with a slow rise at later SOAs (Turvey, 1973).

Metacontrast masking refers to masking caused by an object that is in close spatial proximity to the target object but does not overlap the target (Brietmeyer & Ganz, 1976). Metacontrast masking shows a different temporal pattern than other forms of masking. Metacontrast masking is usually relatively week at a 0ms SOA, and gradually increases with longer positive SOAs. Strongest masking usually occurs at moderate positive SOAs followed by a gradual decrease in masking at later SOAs. Some forward, or paracontrast masking also occurs, but this is effect is usually much weaker.

Classical Theories of Visual Masking

In his review of visual masking research, Kahneman (1968) described two complimentary classes of theories that were responsible for masking: integration theories and interruption theories. Integration theories are based on interactions between the features of the two stimuli before they enter the decision making (i.e. central) phase of processing (Kinsbourne & Warrington, 1962). If two objects are displayed in close enough temporal succession, central processing mechanisms will not have begun working with the visual information about the first object before the visual information about the second object arrives. When this occurs, the final signal processed by the central mechanisms is a single fused, or integrated, object containing the visual information about both the target and the mask objects. Because the integration of two objects is dependent on the two signals combining before the central processing mechanisms have begun working with the first object, the time course of the stimulus presentation determines if a target and mask will become integrated. The ability to make a decision about the target embedded in the combined target/mask object will depend on the ability to separate the features on the target form the features of the mask. The ability to separate the features of the two objects will depend on factors such as the spatial overlap of the features and the relative brightness of the two objects in the displayed.

Interruption theories are based on interactions between the stimuli after they have entered the central, decision making phase of processing separately (Sperling, 1963; Weisstein, 1966). In interruption theories, the central mechanisms have received the visual information about the first object and are processing that information for meaning, but have not finished when the visual information about the second object arrives. The result is that the processing of the information about the first object is stopped, or interrupted, by the arrival of the information about the second object. The result is that the information about the first object is essentially erased from the central processing system before a decision can be made.

Turvey (1973) expanded on the integration/interruption distinction reviewed by Kahneman (1968). He described a division of visual processing mechanisms into two categories based on the neurological organization of the visual system. Peripheral mechanisms include the retina, optic nerve and parts of the striate cortex, and refer to the mechanisms that are responsible for transmitting the visual information from the eye to the brain. The central mechanisms are responsible for working with the information received from the peripheral system. In this model, integration and interruption masking can occur within both the peripheral and central systems. The division of the visual system into two categories is essentially the same concept described by Kahneman (1968) except that the distinction between the type of masking, either integration or interruption, is not as important as where in the visual processing stream masking occurs.

Although heavily based on the neurological structures of the visual system, this model is still an information processing model rather than a neurological model. Turvey (1973) makes the qualification that the differences between peripheral and central mechanisms were not very clear on the neural level, especially within the striate cortex. The important contribution of this model is that it provides a comprehensive description of visual information processing within the framework of the neural structure of the visual system.

At the time that Turvey (1973) developed his model there was strong neurological evidence to support parallel processing of the various components of visual information in the visual system. Hubel & Wiesel (1962, 1965 & 1968) had found that the visual systems of cats and monkeys contain individual neurons that are selectively sensitive to different types of visual information and that this information is transmitted from the eye to the brain in parallel. Turvey (1973) proposed that the peripheral visual system can be described by a neural net model in which different “channels” transfer different characteristics of information – such as the size, shape, brightness and orientation of an object or pieces of an object – in parallel to the central system. These different channels transfer their information at different rates of speed, and the transfer rate within any give channel can change depending on the strength of the original signal from the eye. Further, the activation within any channel does not end abruptly. Rather, the excitatory activity degrades at a certain rate, also depending of the strength of the signal. The stronger the original signal is, the longer it will take to degrade, and therefore the longer the information will persist within that channel.

In a masking experiment, if the masking object follows a target object after only a short onset delay, the excitatory response within any give channel to the target object may still be active when the excitatory response to the masking object begins within the same channel. If this occurs, the two signals will interact with each other. They may sum together, or integrate, so that the information delivered to the central mechanisms by any given channel is the combined signal of both objects. The result is the perception of a single integrated object where the amount of information available will depend on the relative strength of the two signals. Conversely, the signal form the mask may simply overwrite the signal from the target with the result that only the information about the mask will be delivered to the central mechanisms.

The central system is responsible for making decisions about the information delivered by the peripheral system. The different peripheral channels deliver their information to the central mechanisms at different times and the time it takes for any given channel to deliver its information to the central system also depends on the strength of the original signal from the eye. However, the central system does not wait for all of the information about an object to arrive before it begins processing. Rather, it will process the peripheral information in a serial fashion, as it receives it from the various channels. Central masking occurs when the central mechanisms have received and begun processing some, but not all of the information about the target object when information about the masking object arrives from the peripheral system. When this occurs, the information about the target and the mask can either integrate in the central system to form one fused object, or the newer information about the mask object can interrupt and replace the older information about the target object in the central system.

Turvey's (1973) division of the visual system into central and peripheral mechanisms was the result of a series of experiments that measured response accuracies in target identification tasks performed under a variety of viewing conditions. The starting point for his study of visual information processing was the peripheral system. There is a direct relationship between the brightness of a stimulus and its duration. A dim stimulus presented with a long duration (that does not exceed a certain threshold duration) is perceived of as having exactly the same brightness as the same stimulus displayed at a higher luminance for a shorter duration. This relationship is known as

Bloch's law. The implication of this summation of luminance over time is that if two signals of the same duration and intensity are both present in the same channel within a critical temporal window, the luminance of the two separate signals may be summed together to form one integrated signal (Eriksen & Collins, 1965). The summation of luminance over time is presumed to occur within the peripheral system.

In order to investigate the role of the summation of information over time within the peripheral system, the effects of peripheral mechanisms on response accuracy scores must first be separated from the effects of the central system mechanisms on response accuracy scores. Turvey (1973) accomplished this by comparing the results of masking under dichoptic, monoptic, and binocular viewing conditions. Binocular viewing conditions refer to normal viewing conditions; that is, when the all of the stimuli are presented to both eyes. A monoptic viewing condition occurs when both stimuli are presented to only one eye. A dichoptic viewing condition occurs when the target is presented to one eye and the mask is presented to the other eye.

Information about two objects presented under dichoptic viewing conditions cannot directly interact because the information being transferred from one eye cannot directly interact with the information transferred by the other eye until it reaches the central system. Therefore, if visual masking occurs when the stimuli are presented under dichoptic viewing conditions, the observed masking cannot be attributed entirely to peripheral processing mechanisms. Information about two objects presented under monoptic or binocular viewing conditions can directly interact within the peripheral or central systems. If visual masking does not occur when the target and mask are presented under dichoptic viewing conditions, but does occur when the target and mask are presented under monoptic or binocular viewing conditions, then the visual disruption of the target object caused by the presentation of the mask is likely due to interactions that occur within the peripheral processing system rather than the central processing system. If visual masking occurs when the target and mask are presented under dichoptic as well as monoptic or binocular viewing conditions, then the visual disruption of the target object caused by the presentation of the mask can be due to interactions that occur within the peripheral or central processing system.

In experiments I - IX, Turvey (1973) examined the differences between the effects of a noise mask and a structure mask under dichoptic and monoptic viewing conditions. He found that a noise mask does not produce masking under dichoptic viewing conditions but does produce masking under monoptic viewing conditions. However, a pattern mask produces strong masking under dichoptic viewing conditions. He also found that, as reported by Kinsbourne & Warrington (1962), masking by noise was modulated by the brightness and duration of the mask relative to the target. This finding is consistent with the luminance summation as described by Bloch’s law, and is a further indicator that masking by noise occurs primarily within the peripheral system. Structure masking, on the other hand, was mostly insensitive to the relative duration and brightness of the target compared to the mask. Instead, masking seemed to be determined by the onset of the mask relative to the onset of the target (i.e. the SOA). These findings are not consistent with peripheral processing mechanisms, so central processing mechanisms are likely contributing more to the disruption of the perception of target object.

He concluded that noise masking was the result of interactions between the target signal and the mask signal within the peripheral processing system because dicoptic presentation of the stimuli did not produce masking and because masking observed under monoptic presentation of the stimuli was sensitive to brightness and the duration of the mask relative to the target. He also concluded that structure masking was a result of interactions between the target signal and the mask signal within the central processing mechanisms because masking was insensitive to the relative duration and brightness of the target compared to the mask.

In experiments X – XIII, Turvey (1973) investigated the role of peripheral processing in pattern masking. He found that when the duration of both the target and the mask was short, the visual masking produced by a pattern mask was sensitive to the brightness and the duration of the mask relative to the target when presented under monoptic viewing conditions. Also, participants reported that the target appeared to be distorted under these display conditions. However, at longer target durations the visual masking produced by a pattern mask was not insensitive to the brightness and the duration of the mask relative to the target. Further, the critical SOA (the minimum SOA at which the target could be accurately identified) for a structure mask under monoptic viewing conditions was the same as the critical SOA when the stimuli were presented under dichoptic viewing conditions. Finally, rather than reporting distortions in the target object, participants in these viewing conditions reported that they could see the target clearly, but did not having enough time to identify the target. These results supported the argument that there were two distinct mechanisms for visual masking: one based on interactions between information in the peripheral visual system and one based on interactions between information in the central visual system.

In the last seven experiments Turvey's (1973) further examined the differences between central and peripheral processing mechanisms that are responsible for visual masking. He argued that forward masking was generally the result of peripheral processing (experiment XIV). He also observed that peripheral forward masking was stronger than peripheral backward masking (experiment XV) and more sensitive to target duration (experiment XVI). Experiment XVII demonstrated that central forward masking was possible. Experiments XVIII and XIX demonstrated the independence of peripheral and central masking by again showing that masking could still occur under circumstances in which masking should not be possible via peripheral system mechanisms.

Current Theories of Visual Masking

Feed-Forward Visual Processing Theories

Breitmeyer and Ganz (1976) introduced a new model of visual information processing. Their model was a modification and expansion of the neural net based model presented by Turvey (1973). The Breitmeyer and Ganz (1976) model has become one of the most well known models of visual information processing and represents a newer class of models. Turvey's (1973) model of visual information processing was design with consideration of the neural organization of the visual system. The new class of models takes the consideration of the neural organization of the visual system a step further. They were specifically designed to be constrained by the neural organization of the visual system rather than simply taking it into consideration.

Generally, the new class of model describes inhibitory and excitatory interactions between "channels" of visual information. A channel is simply a separable component of visual information and can include (but is not limited to) information such as brightness, color orientation, or the retinotopic location of visual information. According to these models, when visual information is displayed to the eye, signals are generated within the various channels of the visual system that represent the various components of the displayed information. Visual masking is caused by interactions between the signals associated with the display of the first object and the signals associated with the display of the second object. The signals can interact within a single shared visual channel (intra-channel interactions) as well as between different visual channels (inter-channel interactions).

Breitmeyer (1984) provides a review of some individual models (including his own two-channel theory). These models are exclusively feed-forward in nature and generally involve some form of read-in to and read-out from an iconic store. Intra-channel and inter-channel interactions occur prior to the formation of an iconic image (i.e., during the read-in stages), so visual masking is caused by processing mechanisms that occur before the readout from the icon begins. Because masking can not occur once read-out from the icon begins, interruption of visual information processing at the decision making stage is no longer required to explain the various masking effects observed in delayed onset masking paradigms.

Turvey (1973) described the peripheral system as being responsible only for transferring information from the eyes to the central system. In this newer class of theories, the peripheral mechanisms are not simply information transfer mechanisms.

Channels of visual information interact with each other within neural structures that are traditionally thought of as part of the peripheral transfer system (e.g., the lateral geniculate nucleus) as well as cortical areas thought of as part of the central system (e.g., cortical areas V1 and V2). Where as Turvey (1973) described interactions between channels of visual information, what makes the new class of theories different is that they specify the mechanisms of the interactions between and within the visual channels.

The onset of any object with the visual field will cause both excitation and inhibition within any given channel. It will also cause inhibition between one given channel and other neighboring channels. Further, some channels carry information through the visual system faster than other channels. The way in which the various channels interact with each other is determined by the relative onsets of the two objects (i.e. the SOA), whether the signals generated by the onsets of the two objects occupy the same channel or neighboring visual channels, and weather the various signals are active at the same time. If an excitatory signal is active within any given channel when it receives an inhibitory signal (either from the same channel or from a closely neighboring channel), then the excitatory signal will be reduced, or even completely suppressed, by the inhibitory signal. For example, if two identical lines with a very small spatial separation are displayed to the eye at two different times, the onset of first line will generate an excitatory and an inhibitory signal within a spatial location channel. The onset of the second line will generate an excitatory and inhibitory activation within a spatial location channel that is a close neighbor to the spatial location channel carrying information about the first line. If the excitatory activation in the channel carrying the spatial location information about the first line is still active when it receives the inhibitory signal from the neighboring spatial location channel – which is generated by the onset of the second line – then the information about the spatial location of the first line will be inhibited by the spatial location information about the second line. The result would be that the spatial location information about the first line will never reach the central system, so that the final visual perception may be of only one single line at the spatial location occupied by the second line.

If the inhibitory signals generated by one object within a display does not interact with, or does not completely inhibit the excitatory signal generated by the other object, then an integration of the two signals may occur, which will result in the perception of both objects. The signals associated with the display of two objects will not interact if they are not within neighboring channels, or if the SOA of the display is not within an optimal range. To return to the example above, suppose the two lines are displayed on the screen at an optimal SOA (i.e. the signals generated by the two objects are temporally overlapping), but have a very large spatial separation on the screen. Even though the SOA is optimal, the inhibitory signal generated within the spatial location channel by the second line will be too far away from the spatial location channel carrying the information about the first line to affect it. If this is the case, then the spatial location information about both lines will reach the central system and it is likely that both lines will be perceived.

On the other hand, say the two lines in our example are displayed with a small spatial separation, but are displayed either at the same time, or after a very long SOA. In these cases the inhibitory and excitatory signals generated by the onsets of the two lines will be active within neighboring spatial location channels, but they may not be active at the same times. The inhibitory signal generated within the spatial location channel by the onset of the second line will not temporally overlap with the excitatory signal generated within the spatial location channel by the onset of the first line. Again, the result will be that the signals within the spatial location channels will not interact and both signals will reach the central system resulting in the visual perception of two separate lines.

Visual Masking and Feed-Forward Processing

Under feed-forward processing theories, interactions of inhibitory and excitatory signals within channels of visual information are responsible for the various forms of visual masking. An important concept of the inter-channel and intra-channel interactions described in most feed forward models is that the type of interaction (i.e. excitatory or inhibitory) and the strength of the interactions are time locked to the onsets of the two objects. In most feed forward theories the inhibitory signal associated with the onset of an object is described as traveling faster than, or ahead of, the excitatory signals that carry more detailed information.

The visual information about two objects can only sum together if both of the respective excitatory signals are still active within their channels, and the inhibitory component of the signal of one object does not temporally overlap with the excitatory component of the other object. This will only occur with simultaneous onsets, or relatively short SOAs because the two excitatory signals will travel through the visual system at about the same rate. An example of masking via the integration of two signals is masking by noise. If a noise mask is used in a visual masking experiment, and the target and mask are presented either simultaneously, or with a short SOA, then the signals that have the strongest inhibitory effects (i.e., those associated with the onsets of the two objects) will not temporally over lap, but the signals that have stronger excitatory effects will overlap. Since the information about both objects will arrive at the central system at essentially the same time, both objects will be perceived as a single object. In this case, identifying the target would be difficult, if not impossible, because the features of the target will be embedded within the noise mask so that the target is "camouflaged" by the mask. When two excitatory signals sum together in this way, it occurs during the early stages of visual processing (i.e., before binocular combination, as argued by Turvey, 1973).

As demonstrated by Turvey (1973), noise masking does not occur after binocular combination. According to inhibitory based visual processing theories, this is because the channels that carry the information about the contours of the noise mask are not close enough to the channels that carry the information about the contours of the target. In dicoptic viewing conditions the target and the mask are presented to two separate eyes, so during the later stages visual processing (i.e. after binocular combination) the visual system can treat them as two separate objects, even if they are displayed with a short or simultaneous SOA. If this is the case, then even if the mask spatially overlaps with the target, the information about the features of the target can still be separated from the information about the features of the mask. However, this does not mean that the visual channels stop interacting with each other after the binocular combination process.

The integration of the information about two objects can occur after the binocular combination process via the combination of contour information. An example of this is masking by pattern. While channels of visual information can interact with each other prior to binocular combination, visual processing mechanisms at these stages function primarily to transfer information from the eyes to the brain. Visual processing that occurs after binocular combination is more concerned with identifying and separating the features of an object. In masking by pattern the features of the target and the mask become integrated during latter stages of visual processing because the features of the pattern mask are very similar to the features of the target, making them difficult to separate.

One of the advantages of inhibitory based visual processing models over Turvey's (1973) model is that they address the mechanisms of metacontrast masking, which Turvey (1973) did not explore. In metacontrast masking, the features of the target and the mask are very similar – they share the same orientation and are spatially close to each other – but they do not spatially overlap. Because the features do not overlap, even if signals of the two objects become integrated in the peripheral or central systems the target would still be identifiable because the features of the mask will not "camouflage" the features of the target. Turvey's (1973) model would describe metacontrast masking as a case of interruption masking. However, certain aspects of metacontrast masking make interruption of processing a less viable explanation.

First, metacontrast masking has been shown to be sensitive to the relative brightness of the target and mask (Fehrer, 1962). Turvey (1973) described interruption masking as insensitive to the relative brightness of the two stimuli. Also, the similarity of the contours of the target and the mask should have little affect on interruption masking in Turvey's (1973) model because the arrival of information causes the interruption, not the relative qualities of the information. However, metacontrast masking has been shown to be sensitive to the similarities in the features of the target relative to the mask (Hellige, et al., 1979). These findings make it difficult for interruption alone to explain metacontrast masking.

An inhibitory based visual processing model explains metacontrast masking as the result of the inhibition of the visual channels carrying the contour information about the target by the visual channels carrying contour information about the mask. This is known as inter-channel inhibition. Metacontrast masking becomes progressively stronger with increases in the SOA, peaking out at some moderate SOA, and then decreasing at longer SOAs. This temporal pattern reflects the temporal overlap of the excitatory signal produced by the target object and the inhibitory signal produced by the masking object. The magnitude of metacontrast masking depends on the strength of the inhibitory signal generated by the mask relative to the strength of the excitatory signal generated by the target. This can be changed by changing the spatial separation between the contours of the target and the mask, with larger separations producing weaker masking (Kolers, 1962). If the spatial separation of the contours of the target and the mask are farther apart, then the channels that carry the information associated with the two objects will be farther apart, leading to weaker inhibitory interaction between the visual channels.

The relative strength of the inter-channel inhibitory interaction can also be changed by changing the temporal separation between the target and the mask. Because the excitatory signal caused by the onset of an object travels more slowly through the visual system than the inhibitory signal caused by the onset of an object, the inhibition of the target by the mask will only occur if the excitatory signal associated with the target is still active within a visual channel when the inhibitory signal associated with the mask arrives. This temporal overlap is most likely to occur as intermediate SOAs. At early SOAs the excitatory signal associated with the onset of the target is still very strong, so the inhibitory signal caused by the onset of the mask will not have a very strong effect on the excitatory target signal. As the excitatory portion of the target signal travels through the visual system it will slowly degrade, allowing the inhibitory portion of the mask signal to have a stronger affect. At latter SOAs, the excitatory portion of the target signal is more likely to have arrived at the central system before the inhibitory portion of the mask signal has “caught up.” Because the central system is immune to visual masking, no masking will occur.

The retinal location of the target/mask display can also affect the magnitude of metacontrast masking. If the stimuli are displayed outside of the fovea, stronger masking is observed (Alpern, 1953; Merikle, 1980). This is due to the neural organization of the retina. The sizes of the receptive fields in the eye are larger at retinal locations farther from the fovea. This causes the spatial resolution (i.e. the exact location of the contours) of the target and the mask to be less clear. Because the location of the contours are less clear, the signals associated with the contours of the target and the mask are more likely to travel in neighboring channels, or even the same channel, leaving the excitatory signal of the target more vulnerable to suppression by the inhibitory signal of the mask, or integration of the two signals resulting in “camouflage,” as with structure masking. Alternatively, the division of spatial attention may also modulate the spatial resolution of perafoveal information. By displaying information outside of the fovea spatial attention can not immediately be deployed to the target spatial location. This may result in a reduction in the spatial resolution of target information (Breitmeyer & Ogumen, 2006).

Criterion content, that is, the information about the target that a participant is reporting, can affect the temporal pattern of metacontrast masking. When target detection is used to measure metacontrast masking, masking occurs at early SOAs when the target energy is lower than the mask energy (Schiller & Smith, 1966). When brightness ratings are used as a measure of masking, masking occurs at intermediate SOAs (Ogmen, Breitmeyer, & Melvin, 2003), similar to masking in a target discrimination task (Enns & Di Lollo, 1997). Different channels transmit their information at different rates, so it follows that the time points at which different channels will be disrupted will depend on when the channels carrying a particular type of information interact. The time point that different channels interact are reflected in the temporal pattern of judgments made based on different criterion content. For instance, the channels that carry information needed to make a detection judgment may transmit information at a faster rate, so the inhibitory signal in the channels carrying the information about the mask will need to overtake the excitatory signal in the channels carrying the information about the target very quickly. If the SOA is too long then the information about the target needed to make a detection judgment will have arrived at the central system before the inhibitory signal generated by the onset of the mask can overtake it.

Another important feature of most feed forward visual processing models is that the iconic store serves as a barrier between perceptual level processing (i.e. read-in mechanisms) and decision making processes (i.e. read-out mechanisms). This means that in a feed forward visual processing model, the priming of perceptual level information is not possible. Priming of masked information has been observed, but feed forward processing models explain this effect as caused by the priming of iconic read-out processes rather than perceptual level priming (Brietmeyer, 2007). Some updated feed forward models (Ogmen, et al., 2003) as well as some newer visual information processing models (Grossberg & Mingolla, 1985) have incorporated some form of feed back component, but the iconic store remains a barrier that prevents priming of perceptual level information. In contrast, a feed forward model does allow for the possibility of perceptual level priming.

Feedback Visual Processing Theories

The newest class of visual information processing theories is based on feedback processing within the visual system. The advantage of a feedback approach to visual processing is that it can explain some of the more recent findings in visual masking research that a strictly feed-forward approach finds difficult to account for. Enns & Di Lollo (1997) demonstrated the possibility that higher level visual information can influence lower level visual processing. The Enns & Di Lollo (1997) study showed that a metacontrast mask, made up of features that should render it ineffective as a masking object under feed forward visual processing theories, served as a powerful mask in a delayed onset paradigm when spatial attention was divided. The masking object in this study was made up of four small dots arranged in a notional square pattern that framed, but did not spatially overlap the target. Spatial attention was divided by randomly displaying the objects in one three possible locations within a visual display.

There are two major reasons that four dot masking should not occur according to feed forward theories. First, the feed forward mechanisms that cause masking are only effective if the two objects have at least some common features, such as similar contours.

The two objects in this study should not have enough features in common, so the activation within any given channel caused by the onset of the mask object would not interact with the activation caused by the onset of the target object within any visual channels, even if the target-mask SOA is optimal. Secondly, in feed forward theories, if the excitation produced by the onset of a masking object within any visual channel is weak (e.g. the mask has limited contours, or has a low perceived luminance), then its accompanying inhibitory signal will also be weak (Turvey, 1973; Breitmeyer, 1984). In the Enns & Di Lollo (1997) study, the target objects were large, high contrast figures, which should generate strong excitatory signals. According to feed forward models, the inhibitory signal that would be generated by a four dot mask should be too weak to suppress the stronger excitatory signal generated by the target. The result should be that even if the respective visual channels were close enough to interact with each other, and the target-mask SOA was within an optimal range, the inhibitory signal in visual channels carrying the information about the mask should not be strong enough to suppress the excitatory signal in the channel carrying the information about target.

Because spatial attention was the key factor in what Enns & Di Lollo (1997) termed object substitution masking, feed-forward processing may be able to explain the results of the Enns & Di Lollo (1997) without resorting to feed back processing. Stronger metacontrast masking occurs in spatial locations outside of the fovea (Alpern, 1953). As discussed above, this may be explained by a reduction in the spatial resolution of perceptual level information when an object is presented in unattended parafoveal locations. Reduced spatial resolution of both stimuli may allow the two objects to share enough features to allow for inter- and intra- channel interactions.

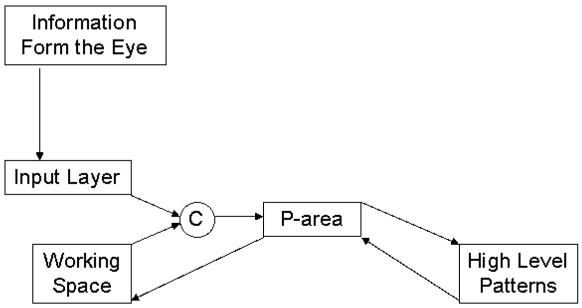
However, in a follow up to Enns & Di Lollo (1997), Di Lollo, et al., (2000) argued that the reduction of the spatial resolution of the *perceptual level* information about the target caused by the division of spatial attention makes the target information more vulnerable to substitution by an *object level* representation of the mask.

Di Lollo, et al., (2000) more closely examined the possible processing mechanism for object substitution masking. The model of visual processing proposed by Di Lollo, et al., (2000) is based on reentrant neural connections within the visual system. A reentrant connection is a two way connection between two groups of neurons, or nodes, within a neural network. When one node becomes active it sends information to a second node via the ascending component of the connection. When this second node becomes active, it sends information directly back to the first node via the descending component of the connection. It is known that extensive reentrant neural connections exist throughout the visual processing system (Felleman & Van Essen, 1991).

The object substitution model describes an iterative re-entrant processing system that is divided into two major components (Di Lollo, et al., 2000). The first component is a local loop system that is responsible for processing the perceptual level information about an object. The information within the local loop system is used to form initial higher level (i.e. object level) representations. The second component is a global loop system. This system is responsible for finding a higher level (i.e. object level) pattern that is consistent with the information in the local loop system, and then comparing the found higher level pattern to the lower level information. The iterations within the local loop system occur very quickly, so the information about a displayed object is continuously updated with new information form the eyes. However, the iterations in the global loop system are relatively slow. This means that if the display changes at some point between the beginning and the end of any given global loop iteration, then there will be a mismatch between the information in the local loop system and the higher level pattern match found by the global loop system when the comparison is made. If this mismatch occurs then the higher level pattern match will be rejected and the search will continue using only the new information.

In a masking paradigm, the initial object level pattern match will be based on the information about the target (or the target/mask pair in the case of a common onset masking paradigm). If the information in the display has changed when the comparison is made between the global loop and the local loop system, then the initial object level representation of the target will be abandoned and replaced, or substituted by the object level representation of the mask. The likelihood that a mismatch between the global loop information about the target and the local loop information about the target will occur depends on the amount of information about the target remaining in the local loop system. Figure 1 shows the basic components and structure of the object substitution model.

Figure 1:



Schematic diagram of the Local and Global loop systems. The local loop system includes the Input Layer, the Working Space, and the P-area. The Global loop system includes the P-area and the High Level Pattern area.

The Local Loop System

The local loop system described by Di Lollo, et al., (2000) involves communication between local brain areas (i.e., between brain areas within the visual cortex). During the local loop cycle, information from the eyes is placed into an input layer. The input layer is part of the primary visual cortex (V1) and functions as a short duration sensory memory store that is constantly updated as new information arrives from the eye. It possesses a retinotopic organization and is made up of very small receptive fields. One way to understand the structure of the input layer is to compare its organization to the organization of pixels on a computer monitor. Each receptive field is analogues to a pixel on a computer monitor. Each pixel contains all of the visual information that is present at that particular location. Because each pixel is organized in the correct location relative to other pixels, the pattern that the pixels form can be perceived as a whole picture rather than as a collection of unrelated dots. Because the input layer is organized in a similar manner it contains the information about each pixel (i.e., receptive field) as well as the spatial relationship between each receptive field.

However, each receptive field in the input layer is independent (i.e., the receptive fields are not directly connected), so the input layer is not sensitive to pattern information.

In order to organize the input layer into patterns, the input layer sends its information to the pattern, or P-area. Di Lollo, et al., (2000) describes the P-area as part of the extra-striate cortex (possibly area V3 and V4, though the exact neural correlates are not specified by the model) which consists of stored pattern information. The P-area patterns that are activated are those that are consistent with the information in the input layer. P-area patterns are not necessarily whole, or complete patterns. Instead, they can be thought of as conjunctions of features such as color, orientation, and spatial location (Treisman & Gelade, 1980). For instance, if a red diamond is presented to the eye (Figure 2, a.) one P-area pattern associated with the diamond may simply consist of a diagonal red line at a particular place in the visual field (Figure 2, b. & c.). This P-area pattern does not contain higher level pattern information, so this red line may or may not be connected to another red line (as in Figure 2, d.). All that is known is that there is a diagonal red line at that location in the visual field. The initial P-area patterns that are activated may be unclear, or more than one P-area pattern may have been activated. In order to clarify these possible ambiguities, the activated P-area patterns need to be compared to the information in the input layer. To accomplish this, the activated P-area pattern, or patterns are placed into a working space.

Like the input layer, the working space is part of the striate cortex, is organized retinotopically, and it contains small receptive fields. It is also continually updated with new information, except that it is updated with P-area patterns rather than with visual information from the eye. P-area patterns have larger receptive fields and are sensitive to the spatial relationships among the smaller receptive fields in the input layer. However, this sensitivity to patterns comes at the cost of spatial resolution. This means that a direct point by point comparison between P-area activations and input layer information is not possible. In order to compare P-area patterns to input layer information, the P-area patterns are place into the working space. The working space now contains a copy of the P-area pattern, but the pattern is now in the form of a pixel like representation that can be directly compared with the information in the input layer. Each time new P-area patterns are activated and placed into the working space, the old working space information is overwritten with the new P-area patterns.

After the P-area pattern is placed into the working space, the working space information is combined with the information in the input layer. This combined information is then sent back to the P-area. A new P-area pattern is activated during this second iteration and then placed back into the working space, where the old working space information is overwritten. As long as the input layer information and the working space information are consistent at the comparison stage of each processing loop, clearer (i.e., less ambiguous) P-area patterns will be activated after each iteration. This iterative cycle will continue until a decision about the visual information is made.

If at some time during the iterative process the input layer is empty when a comparison is made with the working space (i.e., the visual information is removed from the display), then the result of each comparison stage will be made up of only the working space information. As long as the input layer remains empty, the iterative cycle will continue with only the working space information activating P-area patterns. However, without input layer information to reinforce the working space information during the comparison stage, the information in the working space will begin to degrade due to the addition of “noise” during the combination stage of subsequent iterations.

Alternatively, if the input layer information changes at some time during the iterative process, as would occur in a masking experiment, then the input layer will contain information about the mask, but not the information about the target. When this occurs, the working space information about the target would be combined with the input layer information about only the mask. The exact mechanism of the combination stage is not specified by the object substitution model (Di Lollo, et al., 2000), but the information within the input layer and the information within the working space can interact during this stage. The information about the mask in the input layer can interact with the information about the target in the working space in such a way as to reduce the clarity of the target information. When new P-area patterns are activated by this combined input layer/working space information, the P-area activations associated with the target will be less clear because the information about the target after this combination stage will be less clear. This less clear P-area pattern is then placed into the working space. After each iteration of the local loop system in which the target information is absent form the input layer, but the mask information is present in the input layer, the P-area area activations and the subsequent working space information about the target will become progressively less clear.

The extent of the disruption of the target information caused by the mask information within the local loop system will depend on the same stimulus parameters as is described in the literature, such as the relative brightness of the stimuli (Fehrer &

Smith, 1962), and the degree of similarity between the contours of the masking object and the contours of the target object (Houlihan & Sekuler, 1968).

The target and the mask only interact at the combination stage of the local loop cycle. If the mask is presented with at a short SOA and a relatively short duration then the mask information in the input layer will begin to interact with the target information in the working space before the target information has degraded (i.e., the target signal will still be relatively strong). This means that the information about the target will not be as degraded as it would have been if the mask had been present at a later SOA (i.e., when the target information had already been degraded due to the addition of noise). On the other hand, if the mask is presented with at a long SOA, then a decision about the target may have been made by the time the contours of the mask begin to affect the information about the target during the combination stage, so these local loop interactions will have no effect on response accuracy scores.

If the metacontrast mask is presented at an optimal SOA, then the target will already be degraded due to the addition of "noise" prior to the onset of the mask. This means that the working space information about the target will be relatively weak, while the input layer information about the mask will be strong. This leaves the information about the target more vulnerable to interactions with the contours of the mask during the combination stage. The result is that the contours of a metacontrast mask will have a much stronger affect on the working space information about the target at optimal SOAs.

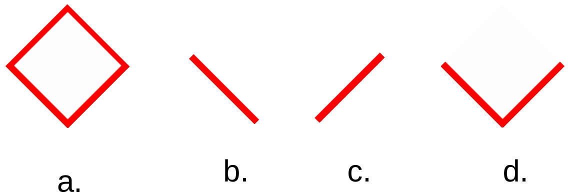
The mechanisms described in the local loop system in the object substitution model produce the same patterns of masking described by feed-forward processing mechanisms. This is because the combination stage in the object substitution model functions the same way as the time locked inhibitory mechanisms described by feed-forward models. However, the local loop processing described by the object substitution model does not account for four dot masking. Four dot masking occurs within the global loop system.

The Global Loop System

The second component to the object substitution model described by Di Lollo, et al., (2000) is the global loop system. The global loop system involves communication between the visual cortex and brain areas outside of the visual cortex. The function of the global loop system is similar to that of the local loop system. The local loop system compares P-area patterns to input layer information. The global loop compares the information in the local loop system to higher level pattern information stored outside of the visual cortex. These higher level patterns are involved in making decisions about the information in the local loop system.

When a new iterative cycle begins in response to new information, initial P-area patterns are activated and placed into the working space. These same P-area patterns are also sent to the higher level pattern areas outside of the visual cortex in an attempt to find initial higher level patterns that are consistent with the P-area activations. As described above, P-area patterns activated during the local loop system have relatively small receptive fields (Figure 2, b. & c.). The higher level patterns stored outside the visual cortex have larger receptive fields and are sensitive to these more complex patterns (Figure 2, d.), but the greater gain in sensitivity to patterns of visual information is accompanied by a greater loss in spatial resolution.

Figure 2:



Information about a displayed stimulus, a,. contained in the P-area, b. & c., and the higher level pattern area stored outside of the visual cortex d.

The ascending component of the reentrant connection associated with the global loop sends P-area information to the higher level pattern area in an attempt to find matching high level patterns. When a match is found, the descending component of the reentrant connection sends information back to the P-area in order to make a comparison between the activated high level pattern and the information in the local loop system. The descending component also adjusts the size of the receptive fields of the P-area so that the P-area activations become more sensitive to complex patterns and less sensitive to smaller changes in the spatial resolution of the information in the working space.

The comparison stage is also adjusted so that more weight is given to the working space information during the comparison stage. The global loop iterations are slower than the fast loop iterations, so any changes in the input layer that occur after the global loop cycle begins, but before the global loop cycle is complete can interfere with the ability to completely process the information at the target location. For example, if the target object has moved, or it the eye has moved, then the target object will no longer be present at the same location in retinotopic space. This would lead to a mismatch between the information at the target location in the working space and the information at the target location in the input layer. The mismatch between the input layer information and the working space information during the comparison stage would lead to different P-area activations associated with the target object. A difference in the P-area activations associated with the target would lead to a mismatch between the new P-area activations associated with the target and the high level patterns activated during the previous global loop iteration. This mismatch would cause the global loop to abandon the original pattern match before a decision can be made, and start over with the new P-area activations. The purpose of these adjustments is to add stability to the iterative process.

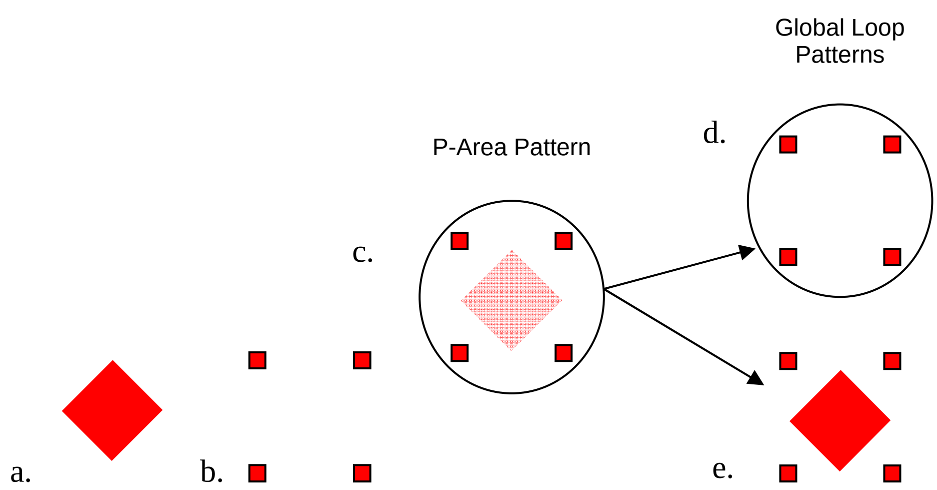
By adjusting the comparison stage so that the working space is more heavily weighted, small or transient changes in the input layer information occurring during latter iterations can be filtered out, leading to a greater stability in the P-area activations associated with the target after each of these local loop iterations. Adjusting the size of the receptive fields of the P-area results in even more stability in the pattern of the information about the target because larger receptive fields are more sensitive to larger changes in the combined working space/input layer information (i.e. changes in the over all pattern of the information), but less sensitive to smaller changes, such as small changes in the spatial locations of the contours of the target object. The iterative reentrant processing is a hill climbing process in which the visual system becomes progressively more sensitive to the pattern of visual information, and less sensitive to the fine grained spatial resolution of visual information. This gives the global loop systems more time to find a stored, object level pattern that is consistent with a relatively stable lower level, P-area patterns activated by the display of information at a target location, and then compare them in order to find the best match.

Masking by Object Substitution

The global loop iterations are slower than the fast loop iterations, so any changes in the input layer that occur after any global loop iteration begins, but before that global loop iteration is complete, will result in a mismatch between the activated high level pattern and the information in the local loop system. When this occurs, the activated high level pattern is rejected and a new high level pattern is found. Object substitution masking is the result of such a mismatch between higher level patterns and lower level patterns. The initial high level pattern activated during a given global loop iteration will contain information about the target as long as the information about the target in the local loop system is above a certain threshold relative to the mask. However, if the information about the target in the local loop system has dropped below that threshold, then the initial high level pattern containing information about the target will be rejected and a new high level pattern will be found that contains only information about the mask. Decisions about visual information are made based on these high level pattern matches, so if a confirmed high level pattern does not contain any information about the target, then the target will be perceptually invisible. If a confirmed high level pattern does contain information about the target, but not enough information to make the decision required by the task, then the target may be visible, but an accurate decision will be impossible.

Figure 3 shows a graphical example of object substitution masking during a common onset paradigm. A target/mask pair is displayed at a random location on the screen for a brief duration and then turned off (Figure 3, a & b). After the target is turned off, the mask remains on the screen. The information about the target within the working space then begins to degrade due to the addition of noise, and possibly some interaction with the mask information. At the same time, the global loop is attempting to find a high level pattern match that is consistent with the initial information about the target/mask pair. However, by the time a high level match is found the information about the target will have degraded, where as the information about the mask will still be clear (Figure 3, c). This initial high level pattern will have contained information about the target (Figure 3, e), but if the information about the target in the local loop system has degraded below threshold then this initial high level pattern will no longer be consistent with the information in the local loop system. This initial pattern will be rejected and a new high level pattern will be found (Figure 3, d) that is consistent with the new information in the local loop system.

Figure 3:



Example of object substitution masking. (a). is the target object.(b) is the mask. (c) it the P-area activation associated with the target mask pair with an optimal SOA (if a delayed onset paradigm is used) or an optimal mask duration (if a simultaneous onset paradigm is used).(d) and (e) are the two possible high level patterns associated with the target mask pair. If the target and the mask are processed as the same object, then d. is more consistent with c. than is e. because the P-area activations associated with the target in c. are below threshold as compared to the mask. The result is that high level pattern d. will be selected and substituted for P-area pattern c. in conscious perception.

It is important to note that object substitution masking is not dependant on the onset or duration of the mask. All that is required for object substitution masking to occur is that there is a mismatch between the local loop information and the global loop information when the comparison between them is made. This can be achieved with the delayed onset of a short duration four dot mask, as long as the mask is displayed before the comparison between the global loop information and the local loop information is made (Enns, 2004; Enns & Di Lollo, 1997).

It is also important to note that the Object Substitution is a general visual information processing model and does not only occur when a four dot mask is used. If a metacontrast mask is used the Object Substitution predicts the same outcome as is normally observed in metacontrast masking. The contours of a metacontrast mask will interact with the contours of the target at the combination stage of the local loop cycle. This interaction will cause an increase in the rate of degradation of the target within the working space which will leave to target more vulnerable to object substitution masking.

Attention and Object Substitution:

Enns & Di Lollo (1997) and Di Lollo, et al., (2000) demonstrated that four dot object substitution was modulated by spatial attention. Enns & Di Lollo (1997) reported that no masking was observed under focused attention conditions (i.e., when all stimuli appeared in the center of the screen). Di Lollo, et al., (2000) reported that when attention was divided by randomly displaying a single target/mask pair at one of eight possible locations on the screen, only very weak masking was observed, meaning that simple spatial uncertainty was not enough to produce four dot object substitution masking.

However, when the target set size was increased by displaying multiple possible targets on the screen to serve as distracters, with the to be reported target indicated by the four dot mask, strong masking was observed. The strength of the masking effect (as reflected by a drop in response accuracy scores) increased with the number of distracting targets. This increase in masking was greatly reduced or eliminated if a valid spatial cue was presented before the target display was turned on.

Di Lollo, et al., (2000) explained these findings as caused by a delay in the ability to focus attentional resources on the correct target location. This delay, in what Di Lollo, et al., (2000) termed time to contact, results in a loss of spatial resolution of the information at the target location if attention cannot be immediately engaged. In order to identify the target in a masking experiment, a participant must first determine the spatial location of the target. This means the participant must first find the mask. When the mask is found, spatial attention can then be shifted to the location of the target/mask pair. The visual system must then determine which features at that spatial location belong to the target/mask pair and which belong to any other information with in the same general area (i.e., any distracter targets). Once the target/mask pair has been isolated, this information can be processed with the exclusion of all other information in the display. This delay in the time to contact with the target location will lead to less clear initial P-area activations as well as an increase the time required to find a higher level pattern match for the target. This means that the initial local loop information about the target will be less clear, and will have had more time to degrade before a higher level pattern match can be found, which will leave it more vulnerable to object substitution when the comparison is finally made. Increasing the number of distracters in the display increases the time it takes to separate the information at the target location form the other information in the display, which effectively increases the time to contact with the target location.

Object level representation within the Object Substitution Model

In the global loop cycle of the object substitution model, a high level pattern is selected based on the information within the local loop system. This high level pattern is then confirmed by comparing it to the low level information. Another way of understanding this process is to think of visual processing as a series of hypothesis tests. A P-area activation during the local loop cycle is an hypothesis about the pattern of the combined input layer/working space information within a very small area of the visual field. A high level pattern selected during the global loop cycle can be thought of as a perceptual hypothesis of the pattern of information within the local loop. Because a high level pattern contains more complex pattern information than is contained in P-area patterns, a high level pattern can be thought of as a hypothesis about the object at the selected location.

Object substitution masking is caused by a rejection of an object level perceptual hypothesis due to a mismatch with local loop information. One of the key requirements for object substitution masking is that the original object level perceptual hypothesis about the information at the target location target must be of one single object made of the target and the mask rather than two separate object level perceptual hypotheses. If the target and the mask can be represented as two separate level perceptual hypotheses, then object substitution masking is greatly reduced or eliminated. More & Lleras (2005) conducted a study using a common onset four dot masking paradigm in which color and motion were used to separate the object level representation of the target from the object level representation of the mask. The results indicated that when the target and mask patterns can be clearly represented as two separate objects, rather than being part of the same pattern or object – by changing either the color of one of the objects, or by having one of the objects move independently of the other in the visual display – then the strength of masking is greatly reduced.

However, even though object substitution masking is dependant on the selection of object level patterns, this does not mean that these object level patterns are categorical in nature. Recent work has shown that the object level patterns responsible for object substitution masking are pre-categorical. Reiss (2006) examined ERP recordings of the n400 signal recorded in response to masked semantically incongruent words. Reiss (2007) examined ERP recordings of the n170 signal recorded in response to masked faces. In both of these studies, the ERP signal normally associated with the categorization of the respective stimuli (i.e. semantic word meaning in the case of the n400, and categorization of a face object as a face in the case of the n170) was suppressed by a four dot mask in a common onset masking paradigm. These findings indicate that the object level patterns involved in object substitution masking are pre-categorical.

Priming of Perceptual Level Information

While the discovery of four dot common onset masking has produced a strong argument for the existence of extensive feed back in visual information processing (Di Lollo, et al., 2000), predominantly feed forward visual processing models cannot be ruled out. However, the barrier between perceptual level processing and decision level processing imposed by most current feed forward based theories is a limiting feature that is not shared by a model that incorporates extensive feed back processing, such as the Object Substitution model. If the barrier between perceptual level processing and decision level processing can be breached, it would be difficult for current predominantly feed forward processing models to account for the breach without resorting to the incorporation of more extensive feed back components. The demonstration of priming of perceptual level information that can not be explained by decision making processes would be a breach in the barrier of the iconic store.

The hypotheses about the pattern of visual information that are being tested in the object substitution model in both the local and global loop components are currently described as being based only on new the visual information coming in from the eyes at the start of a new trial (Di Lollo, et al., 2000). If this is the case, then the visual processing of stimuli displayed in one trial of a masking experiment will have no effect on the visual processing of stimuli displayed in following trials. However, if the processing of an object in a new trial can be influenced by perceptual hypotheses formed during the processing of previously displayed objects, then previously displayed stimuli can affect the processing of new visual information.

In a typical masking experiment, participants are repeatedly presented with and responding to the same set of target stimuli. During each trial a participant will form a high level perceptual hypothesis about the target presented in that trial. If this high level perceptual hypothesis can remain available across multiple trials, then it can be thought of as a long term perceptual hypothesis. This long term perceptual hypothesis may be able to affect the processing of new visual information. One way of affecting the processing of the visual information in a new trial is by priming local loop patterns (i.e., P-area patterns) that are consistent with the long term perceptual hypotheses. This can be accomplished by using the descending component of the global loop system. Alternatively, if a long term perceptual hypothesis is consistent with the a target displayed in a new trial, then when the initial local loop information about the new target reaches the high level pattern area it is more likely that the already primed high level pattern will be selected. This means that the high level pattern areas will be more sensitive to the pattern if information in the local loop system if the local loop information is consistent with a long term perceptual hypothesis. The result is that even information about the target within the local loop is relatively the weak it will still be enough to confirm a high level perceptual hypothesis that contains information about the target. Some combination of these two mechanisms is also possible. Regardless of which system is being affected, the existence of a long term perceptual hypothesis would result in the enhancement of the processing of new visual information that is consistent with the long term perceptual hypothesis.

The existence of priming can be confirmed by comparing the results of a visual masking experiment in which a large number of long term perceptual hypotheses are formed with the results of a visual masking experiment in which fewer long term perceptual hypotheses are formed. If long term perceptual hypotheses can be used to enhance the processing of new information via the priming of pattern information, then increasing the number of primed patterns will likely lead to increased competition for activation among the primed patterns. This would result in less effective enhancement of the visual processing of new information when more long term perceptual hypotheses are present. This loss of effectiveness will leave the target more vulnerable to object substitution masking, which would be reflected as a drop in response accuracy scores.

In the present study the number of long term perceptual hypotheses is manipulated by changing the number of possible target identities that a participant may see on any given trial. In one condition participants performed a two alternative forced choice (2AFC) task in which participants must choose between two possible target identities. The task was to report the location of a missing corner of a diamond shaped object. This is the same task and the same stimuli used by Enns & Di Lollo (1997). The target in any given trial of the 2AFC response condition was missing its left or right corner, and participants pressed a key on the keyboard that corresponded to the location of the corner (i.e., there were two possible responses). Response accuracy scores in this task were compared to response accuracy scores of participants in a four alternative forced choice (4AFC) task. The same stimuli were used in this 4AFC response condition except that the diamond object could be missing any one of its corners. The perceptual level of information about the target was identical in both conditions, so it is unlikely that differences is the figural makeup of the target object would cause any differences in the processing of the target in any given trial of either condition. In other words, the amount and quality of perceptual level information about the target available for decision making in any given trial of the 2AFC condition should be exactly the same as the amount and quality of perceptual level information about the target available for decision making in any given trial of the 4AFC condition. The only difference between the two response conditions was the number of possible long term perceptual hypotheses available.

However, increasing the number of possible choices that a participant can make may affect cognitive mechanisms, such as response level processing, that are separate from perceptual and decision level processes but may also affect response accuracy scores. In order to account for the possible confound of response level processing as a source of “masking” (i.e., a factor that may affect response accuracy scores), a third response condition was implemented. In this response control (RC) condition the 4AFC condition was essentially transformed into a 2AFC response task by a simple manipulating of the task parameters. In the RC response condition the display was exactly the same as in the 4AFC condition: participants were presented with one of four possible diamonds. However, they only needed to make one of two possible responses: if the top or left corner of the diamond was missing participants made one response, and if the right or bottom corner was missing participants made another response. Participants in this response condition will have formed the same number of long term perceptual hypotheses as participants in the 4AFC response condition, but will only have to make the same number of responses as participants in the 2AFC response condition. If response level processing is responsible for, or significantly contributing to the predicted drop in response accuracy scores in the 4AFC response condition as compared to the 2AFC response condition, then response accuracy scores in the RC response condition should be closer to those in the 2AFC than those in the 4AFC response condition because the number of response is the same in the RC and 2AFC conditions. If response level processes are not significantly contributing to the predicted increase in masking in the 4AFC response condition, then response accuracy scores in the RC response condition will be closer to those in the 4AFC response condition because all other variables are the same in the RC response condition as in they are in the 4AFC response condition.

The time course information provided by visual masking experiments may provide additional clues to the predicted differences in processing between the three response conditions used here. A common onset paradigm is used in both experiments in this study in order to better eliminate onset dependent inter- and intra- channel interactions between the target and the mask, allowing for better interpretability under the object substitution model. Differences in decision level processing may be revealed by examining differences in the time course of visual masking. Decreases in the time course of masking my reflect decreases in the time required for decision making. If this is the case then it may be possible to separate the time course of decision making form the accuracy of decision making. The ability to separate the time course of decision making from the accuracy of decision making is important because it may allow perceptual level processing to be separated form decision level processing. By separating the time course of decision making form the accuracy of decision making it may be possible to separate perceptual level priming from decision level priming.

The final consideration when examining perceptual level priming in an object substitution masking paradigm is the role of spatial attention. Spatial attention modulates object substitution masking because in order to identify the target object, the information at the target location must first be separated form the information at other target locations. The same may be true of the priming of perceptual level information. The visual cortex is organized retinotopically, so in order to prime local loop patterns (i.e. P-area patterns) it is likely that a spatial location must first be selected in order for local loop priming to occur. If a spatial location is not known prior to the onset of the target information, it may be impossible to prime local loop information. A common onset masking paradigm was used in Experiment 2 in order to explore this possibility.

Methods Section

Experiment 1

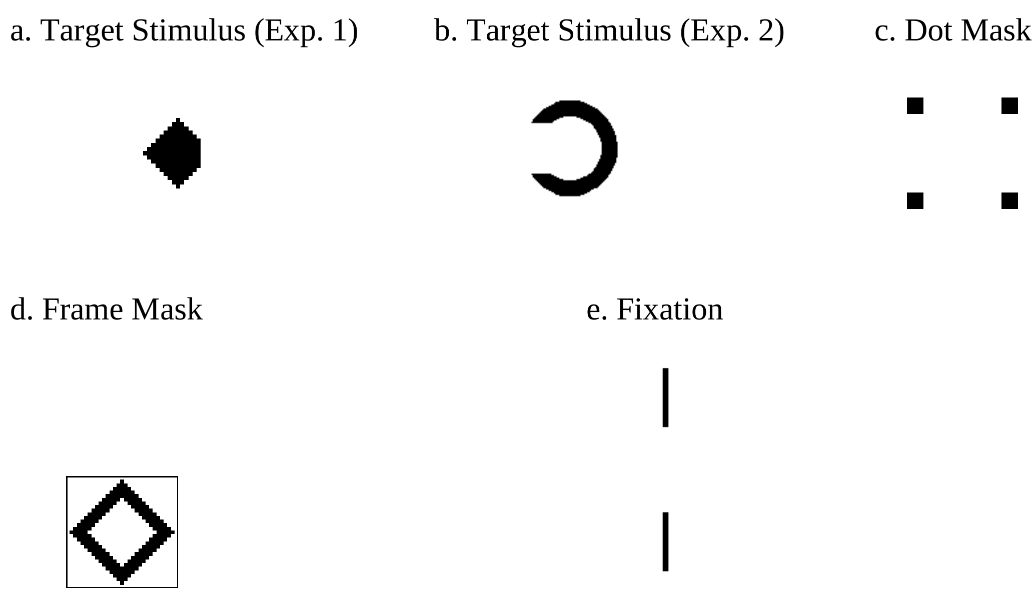
Stimuli and Apparatus

The stimuli were displayed on a Panasonic PanaSyncE110 color CRT monitor with a 20” diagonal viewable image size. The vertical frequency was set to 85 Hz by a Matrox MGA-G200 AGB video adapter, resulting in a minimum stimuli display time of 12 ms. The viewing distance was set to 60cm from the monitor by a chin rest. Screen resolution was set to 1024 X 768. All three experiments were conducted in a darkened room (the lights were turned off). Under darkened conditions, the stimuli were black ($0.00 cd/m^2$) displayed on a white background ($62.04 cd/m^2$). Luminance measurements were taken using a Minolta LS-110 light meter.

The target stimulus (Fig. 4a) was a diamond with a size of .65 degrees of visual angle (17 pixels) at the largest diameter (i.e., from the left corner to the right corner). The missing corner was .078 degrees of visual angle (2 pixels inward) in size. The four dot mask (Fig. 4c.) was 1.03 degrees of visual angle (27 pixels) in size from left to right. Each dot was a square, .078 degrees of visual angle (2 pixels inward) in size and was separated from the target by .191 degrees of visual angle (5 pixels) from its closest edge. The metacontrast mask (Fig. 1d.) was 1.109 degrees of visual angle (29 pixels) in diameter and .191 degrees of visual angle (5 pixels) thick. The mask was separated from the target by 1 pixel. The fixation target (Fig. 1e.) consisted of two horizontal lines, each 2.752 degrees of visual angle (72 pixels) in height and .274 degrees of visual angle (7 pixels) wide. The lines were positioned at the center of the screen and separated by 3.975 degrees of visual angle (104 pixels).

Participants made their responses using the number pad on a standard keyboard. The keys were labeled according to the response condition. In the two alternative forced choice condition the “4” key was labeled “left” (i.e. the left corner of the diamond was missing), and the “6” key was labeled “right.” In the four alternative forced choice condition the “8” key was labeled “top” and the “2” key was labeled “bottom.” For the response control condition, the “7” key was labeled “RT,” meaning that either the right or the top corner was missing. The “3” key was labeled “LB,” meaning that either the left or the bottom corner was missing.

Figure 4:



Stimuli used in experiments 1 and 2.

2 Alternative Forced Choice Response Condition

Participants

Twelve naïve observers participated in the experiment. Participants were age 18 to 21 (M = 19) and consisted of 7 males and 5 females. All participants had normal or corrected to normal vision as determined by self report and three visual acuity tests including contrast sensitivity, near acuity, and far acuity measures. Participants were selected from the University of Kansas psychology research participation pool and received class credit for their participation.

Procedure

After giving informed consent, visual acuity measures (described above) were collected from each participant. Participants were then brought into the room where the experiment was conducted. The door was then closed and the lights turned off. Participants' eyes were allowed to adjust to the luminance conditions in the room as the experiment instructions were given. Either the left corner or the right corner of the target stimuli was missing. The participants' task was to indicate with a button press which corner was missing in each trial. If unsure they were instructed to give their best guess. Response choices were spatially mapped according to the missing corner in each condition. Figure 2 shows the keyboard layout for all three response conditions. Each participant was told that only the accuracy of their response was important and that the speed of their response was not important.

Figure 5:

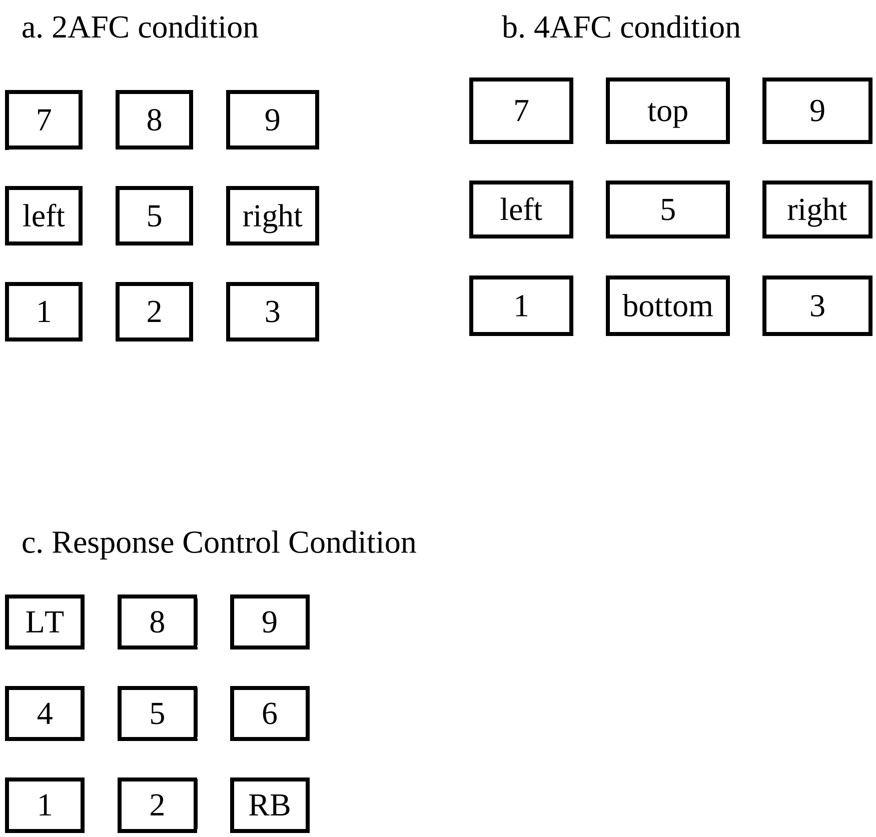


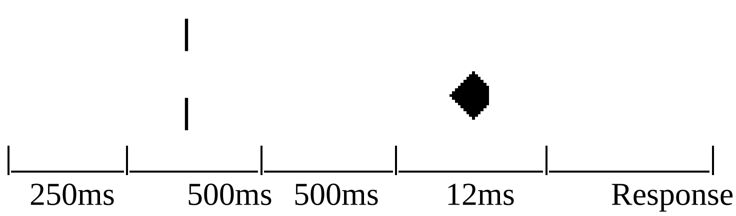
Figure 5 shows the spatial arrangement of the response keys used in a. the 2AFC response condition, b. the 4AFC response condition, and c. the RC response condition.

The experiment was broken into seven trial blocks. The first three trial blocks consisted of practice trials and the last four blocks consisted of the experimental trials. During the first practice trial block, the target was presented alone in order to familiarize the participant with the experimental task. In all other trial blocks the onset of the target was accompanied by the onset of either the four dot or metacontrast mask.

The first trial in each block was initiated when the participant made a spacebar press on the keyboard when they were ready to begin the block. Each subsequent trial was initiated when the participant made their response in the preceding trial. Each trial began with a 250 ms wait period, during which the screen remained blank. The fixation target was then displayed for 1000 ms followed by another 500 ms wait period during which the screen remained blank. In the first practice trial block the target stimulus (without a mask) was then displayed for 12 ms and then turned off. The participants then made their responses. They were instructed to respond when they were ready and were not prompted to make a response (the screen remained blank for the remainder of the trial). The next trial did not begin until a response was made. During all other trial blocks the masking appeared at the same time as the target. The target remained on the screen for 12ms and was turned off. The mask remained on the screen for an additional 0ms (the mask display terminated with the target), 24ms, 47ms, 106ms, 153ms, 200ms, or 247ms. The stimuli always appeared at the center of the screen. Figure 6 represents the time course of a single trial in the first practice trial block (figure 6a.) and all other trial blocks (figure 6b.).

Figure 6:

a. Time Course of a Trial in the First Practice Block



b. Time Course of a Trial in All Other Trial Blocks

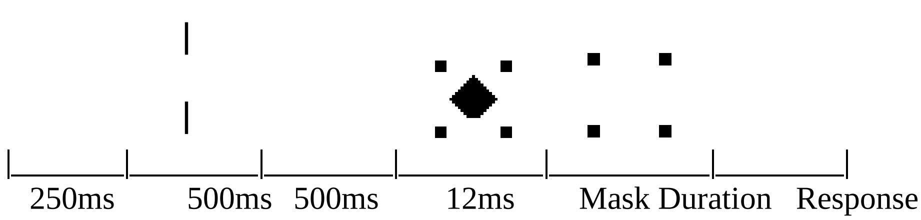


Figure 5 shows the time course of the display in any given trial of a. the first practice block and b. all other trial blocks (both practice and experimental blocks).

The first trial block (target only) consisted of 20 randomized trials. The target was missing the left corner on exactly half (n = 10) of the trials and was missing the right corner on the other half (n = 10) of the trials. The order of second and third trial blocks was counter balanced by participant. For the first six participants, the first practice block consisted of 28 trials during which the four dot mask was presented. Each mask duration was presented an equal number of times (i.e. four times), as was the location of the missing corner. The mask duration and the location of the missing corner were random for each trial. The second practice block was identical to the first, except that the metacontrast mask was presented. For the last six participants, the metacontrast mask was presented in the first practice block and the four dot mask was presented in the second practice. The order of the four experimental blocks was also counterbalanced by subject, with both the four dot mask and the metacontrast mask appearing twice. The mask duration and the location of the missing corner were again random for each trial, and presented an equal number of times. Each of the four experimental blocks consisted of 252 trials. Participants were given a short break between each block. However, they were not allowed to leave the room and the lights remained off. Each experimental block took approximately 15 to 20 min to perform and the entire experiment lasted approximately 2 hr. This procedure resulted in 72 trials per mask duration, per mask type for each participant (practice trials were not included in the analysis). Across all participants, each mask type was presented 864 times at each mask duration.

4 Alternative Forced Choice Condition

Participants

Twelve naïve observers participated in this condition. Participants were age 17 to 27 (M = 19) and consisted of 6 males and 6 females. All participants had normal or corrected to normal vision as determined by self report and three visual acuity tests including contrast sensitivity, near acuity, and far acuity measures. Participants were selected from the University of Kansas psychology research participation pool and received class credit for their participation.

Procedure

The procedure for the 4AFC response condition was exactly the same as 2AFC response condition, except that the target was missing one of four corners in each trial. During any trial, the target was missing either the left, right, top or bottom corner. Participants again responded by pressing a button on the number pad that corresponded to the missing corner.

Response Control Condition

Participants

12 naïve observers participated in this condition. Participants were age 19 to 26 (M = 20) and consisted of 7 males and 4 females. All participants had normal or corrected to normal vision as determined by self report and three visual acuity tests including contrast sensitivity, near acuity, and far acuity measures. Participants were

selected from the University of Kansas psychology research participation pool and received class credit for their participation.

Procedure

The procedure for response control condition was exactly the same as for the 4AFC response condition, except that instead of pressing a button that corresponded to the missing corner, they pressed one button (labeled “LT”) if the left or the top corner was missing and another button (labeled “RB”) if the right or the bottom corner was missing. The “7” key on the number pad was used as the “LT” button. This placed it halfway between “left” and “top” buttons used in the 4AFC condition. The “3” key on the number pad was used as the “RB” button, which placed it halfway between “right” and “bottom” buttons used in 4AFC condition. The procedure allowed the response choices to be spatially mapped with regard to the response task.

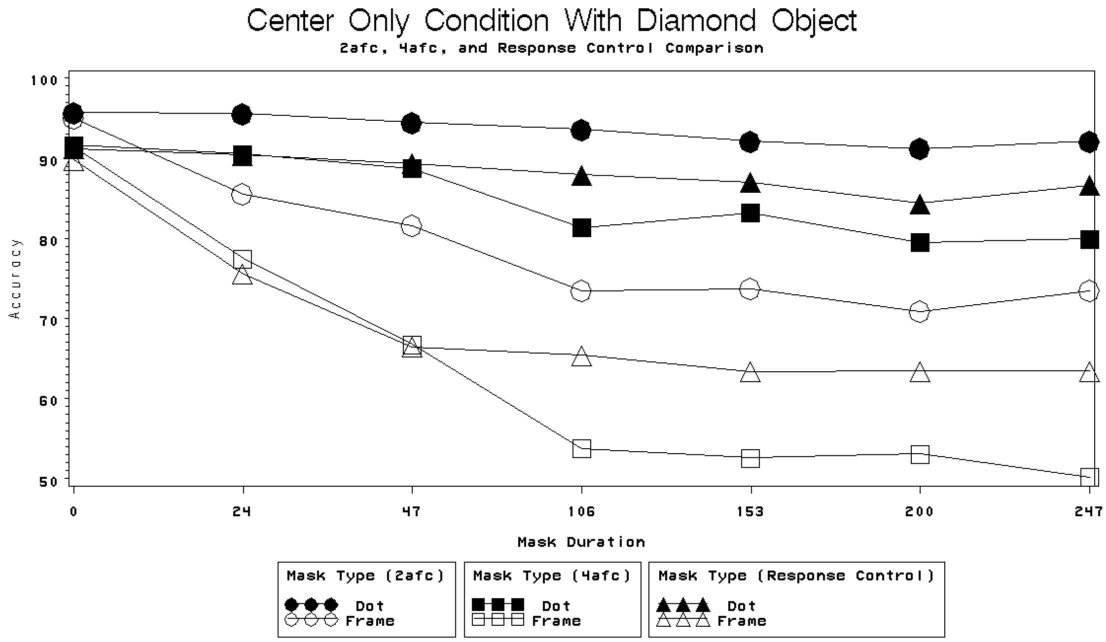
Results

The data were analyzed using a 2 (mask type) X 7 (mask duration) X 3 (response condition) Mixed Linier Model. All main effects and all interactions were significant. For Mask Duration: $F_{(6,198)} = 180.55$, $p < .0001$. For Mask Type: $F_{(1,33)} = 2065.90$, $p < .0001$. For Response Condition: $F_{(2,33)} = 309.2$, $p < .0001$. For Mask Duration X Mask Type: $F_{(6,198)} = 67.57$, $p < .0001$. For Mask Duration X Condition: $F_{(12,198)} = 10.92$, $p < .0001$. For Mask Type X Condition: $F_{(2,33)} = 25.45$, $p < .0001$. For Mask Duration X Mask Type X Condition: $F_{(12,198)} = 2.33$, $p = .0083$.

Post-hock tests for pair wise comparisons between cell means were performed using a Tukey's adjustment procedure. Figure 7 shows the mean response accuracy scores at each mask duration for each mask type in each response condition. For mask durations of 0ms there was no significant difference between the response conditions for the dot mask or the metacontrast mask. For mask durations of 24ms and 47ms there was no significant difference between the response conditions for the dot mask. For all mask durations longer than 47ms, accuracy scores were significantly lower in the 4afc condition than in the 2afc condition for the dot mask. There were no significant differences between the RC condition and the 2afc or the 4afc conditions at any mask durations in the three way interaction. This is likely due to ceiling effects, especially in the 2afc condition. However, post hock comparisons between the RC response conditions and the 2AFC and the 4AFC response conditions were significant when collapsed across mask duration with the 2AFC response condition showing the least masking, followed by the RC response condition, with the 4AFC response condition showing the most masking. This pattern of the differences in the magnitude of masking between the response conditions when a four dot mask was used was a reflection of the pattern of the differences in the magnitude of masking between the response conditions when a metacontrast mask was used. It is difficult to draw conclusions about the temporal pattern of response accuracy scores between the response conditions when the dot mask was used.

For the metacontrast mask, accuracy scores in the 2afc condition were significantly higher than those in both the RC and the 4afc condition for all mask durations longer then 0ms. There was no significant difference between the RC condition and the 4afc condition for either the 24ms or 47ms mask durations. For all mask durations longer than 47ms, response accuracies were significantly different for all response conditions. The 2afc condition showed the highest accuracy scores, followed by the RC condition. The 4afc condition showed the lowest accuracy scores. For all significant differences reported here, p < .01.

Figure 7:



Discussion

Four Dot Masking Under Focused Attention

There was a similar pattern in the magnitude of response accuracy scores between the response conditions for both the metacontrast mask and the four dot mask. Response accuracy scores between the 2AFC and 4AFC were significantly different for both mask types with significantly lower response accuracy scores in the 4AFC condition than in the 2AFC condition, and significantly lower response accuracy scores in the RC condition than in the 2AFC condition. Ceiling effects prevent a full analysis of the temporal pattern of masking in the four dot mask condition. A temporal difference between the 2AFC and the 4AFC was observed, with significantly stronger masking in the 4AFC condition for mask durations longer of 106ms or longer. This is similar to the drop in response accuracy scores in the 4AFC condition compared to the RC condition for mask durations longer than 106ms seen when the metacontrast mask was used, indicating that the temporal pattern of masking between the response conditions may be similar for the four dot mask condition and the metacontrast mask condition. However, because the temporal pattern of masking in the RC response condition cannot be fully examined, this possibility cannot be verified. Four dot object substitution masking has been shown to be modulated by spatial attention (Di Lollo et al., 2000; Enns & Di Lollo, 1997), and because Experiment 1 was conducted only under focused attention conditions, these findings are not surprising.

Four dot masking under divided spatial attention is more closely examined in Experiment 2. However, the mechanisms for masking are the same regardless of the mask type used. The only difference in the visual processing of the target when a metacontrast mask is used, as opposed to a four dot mask, is the amount of degradation of the target information in the local loop system caused by the addition of contour interactions between the two stimuli when a metacontrast mask is used. This becomes evident when the differences in the temporal pattern of masking between the three response conditions using a metacontrast mask are examined.

Magnitude of Metacontrast Masking

For the metacontrast masking conditions, significant differences in the magnitude as well as the temporal pattern of masking were observed. The temporal pattern of masking in the 2AFC and 4AFC conditions was the same, while magnitude of masking observed in the 4AFC condition was much stronger than the magnitude of masking observed in the 2AFC condition. This magnitude difference can be explained in the context of the object substitution model by the priming of local loop information by long term perceptual hypotheses.

During the iterative processing of a target object in the first trial of a masking experiment a high level pattern will be activated by the lower level information associated with the target (Di Lollo et al.; 2000). This high level pattern can be called a perceptual hypothesis because, while it may be consistent with lower level pattern information, it may not be an accurate representation of that information (i.e. an incorrect high level pattern may have been activated by mistake). This problem is addressed by comparing the hypothesized high level pattern to the lower level information. If the high level perceptual hypothesis is confirmed, it may persist through the next, or even subsequent trial begins. If this occurs, then this perceptual hypothesis can be considered to be a long term perceptual hypothesis.

Masking in the 2AFC Response Condition. after a participant performed repeated trials of the 2AFC response condition in the current study, two separate long term perceptual hypotheses about the target object were formed. One long term perceptual hypothesis was a high level pattern consistent with a diamond with its right corner missing. The second long term perceptual hypothesis was a high level pattern consistent with a diamond with its left corner missing. Local loop pattern information (i.e. P-area patterns) that were consistent with these long term perceptual hypotheses were then primed via the descending component of the global loop. These primed P-area patterns were more easily activated by new visual information that was consistent with one of the long term perceptual hypotheses. This means that the initial P-area pattern activations associated with the target were stronger than they would have been if there were no long term perceptual hypotheses priming P-area patterns. Stronger initial P-area pattern activations led to more complete, or less ambiguous, pattern information being placed into the working space during the first iteration. Further, primed P-area patterns remained more sensitive to consistent lower level information throughout the entire iterative cycle. This means that even after the target has been turned off, the remaining working space information about the target more easily activated the primed P-area patterns during subsequent iterations.

Di Lollo et, al., (2000) attributed the decay of working space information about the target after the target was removed form the display to the addition of noise during the combination stage of the local loop. The contours of the metacontrast mask used in this experiment had the additional affect of further disrupting the working space information about the target during each combination stage, which led to a faster degradation of the clarity of working space information about the target over successive iterations. However, because P-area patterns were more sensitive to the working space information about the target, the target information did not degrade as quickly over successive iterations. Because P-area pattern activations associated with the target were primed, the information about the target within the local loop system was more likely to be above threshold when the global loop information arrived for comparison. This meant that a high level pattern that contains information about the target is more likely to be confirmed, leaving the target less vulnerable to object substitution.

Masking in the 4AFC Response Condition. These same priming mechanisms were active for participants in the 4AFC response condition. However, because there were four possible targets in the target set in the 4AFC response condition, four long term perceptual hypotheses were formed. Each of these perceptual hypotheses primed P-area patterns. Because there were more primed P-area patterns, there was more competition for activation among the primed P-area patterns, which led to weaker activations for any one primed P-area pattern over another. This led to less clear P-area patterns being placed into the working space after any given iteration, which resulted in the faster degradation of the information about the target over successive iterations. This increased disruption of the local loop information about the target in the 4AFC response condition as compared to the 2AFC condition led to an increased likelihood that a high level perceptual hypothesis containing information about the target will be disconfirmed when it is compared to the local loop information, thus leading to stronger object substitution masking. This increased competition among primed patterns led to a reduction in response accuracy scored in the 4AFC response condition as compared to the 2AFC response condition.

A feed forward processing theory can explain the difference in the magnitude of masking by cognitive processes that occur after the formation of an icon, meaning that priming of perceptual level information may not be necessary in order to explain the discrepancy in the response accuracy scores between the 2AFC and the 4AFC response conditions. However, a comparison of the magnitude and temporal pattern of masking between the RC response condition and the other two response conditions indicates that decision making processes and response level processes can not account for the difference in the response accuracy scores between the 2AFC and 4AFC response conditions.

Temporal Pattern of Masking: Decision Making

Response accuracy scores in the 2AFC condition are significantly higher than in the 4AFC condition for all mask durations, indicating that more information about the target was available when a decision about the target was made in any given trial in the 2AFC condition than was available when a decision about the target was made in any given trial in the 4AFC condition. However, the temporal pattern of masking was the same in the 2AFC and 4AFC response conditions. This indicates that, while the priming of P-area patterns affected the clarity of P-area pattern activations at the time that a decision about the target was made, priming did not affect the time require to make that decision. Interestingly, the temporal pattern of masking the RC response condition was different from the temporal pattern observed in the 2AFC and 4AFC response conditions, while the magnitude of masking in the RC response conditions was exactly the same as the magnitude of masking observed in the 4AFC response condition.

For mask durations of 0ms to 47ms, response accuracy scores in the RC response condition are exactly the same as those in the 4AFC response condition. This indicates that for 0ms, 24ms, and 47ms mask durations, the same amount of information was available about the target when a decision about the target was made in any given trial of both response conditions. This is consistent with the priming of local loop information. The number of possible target objects that could be displayed in any given trial (i.e. target set size) was identical for both the RC and 4AFC response conditions, so the number of long term perceptual hypotheses formed during the experiment was the same in both response conditions. This means that the same number of competing P-area patterns were primed in both response conditions, so same amount of disruption of the target information occurred during any given trial of both response conditions, which in turn means that the same amount information about the target was available when a decision about the target was made in any given trial of both response conditions.

The masking levels off at shorter mask durations in the RC condition as compared to both the 2AFC and the 4AFC. In order to explain this difference in the temporal pattern of masking, it is helpful to more closely examining what information processing mechanisms that response accuracy scores are actually measuring. This examination allows decision making processes and response level processes to be separated form perceptual level processes, and indicates that the pattern of response accuracy scores observed in experiment 1 can only be adequately explained by the priming of perceptual level information.

The magnitude of a response accuracy score in a visual masking experiment reflects the amount of information available about the target at the time that a decision about that target is made. If it takes longer to make a decision about a target object, then this greater delay will allow the perceptual level information about the target to further decay before a decision is made. This will leave the information about the target more vulnerable to masking, which results in lower response accuracy scores.

The magnitude of a response accuracy score can be thought of as a snap shot of visual information at the time that a decision is made. For example, a decision about the target in any given trial of the 4AFC response condition is made at exactly the same time, regardless of the duration of the mask. If that time point is 118ms after the target was turned on (i.e. the duration of the target/mask pair [12ms], plus the mask duration [106ms]), then the response accuracy score will reflect a snapshot of the information available about the target 118ms after it was displayed.

In the metacontrast mask condition in experiment 1, the contours of the mask interacted with the contours of the target during each combination stage so that the target information degraded more quickly as compared to the use of a four dot mask. If, for example, the metacontrast mask was only present for 24ms, then it will have only a few iterations in which to interact with the target. After the mask is turned off the information about the mask will no longer interact with information about the target and the information about both objects will decay at the same rate. In this case, the snapshot of the target at 118ms will reflect relatively little degradation of the information about the target as compared to the information about the mask. However, if the mask was present for the full 118ms (or longer), then the information about the mask will have many more iterations in which to interact with the information about the target, meaning that the snapshot taken at 118ms will reflect much more degradation of the information available about the target relative to the information available about the mask. Further degradation of the target information caused by mask durations longer than 118ms will not be reflected in the snapshot because the picture has already been taken.

In terms of the snap shot metaphor given above, the temporal pattern of response accuracy scores in a visual masking experiment can reveal when the picture was taken as well as the quality of the picture. In other words, it is possible to observe when a decision about the target was made as well as the accuracy of the decision. With this in mind, the difference in the temporal pattern of masking is relatively independent of the magnitude of masking. In terms of the present study, the same amount of information about the target was available at any given time in the RC response condition as compared to the 4AFC response condition in, but the decision about the identity of the target was made faster (i.e. the snapshot was taken sooner) in the RC than in the 4AFC condition. Mask durations longer than 47ms in the RC condition caused the same amount of degradation of the target information as mask duration longer than 47ms did in the 4AFC condition, but because a decision about the target was already made, this continued degradation of the target information was not reflected in the accuracy scores.

Feed Forward Processing Theories

A predominantly feed forward visual information processing theory can explain either the difference in the temporal pattern of masking, or the difference in the magnitude of masking between the three response conditions implemented in experiment 1, but it can not explain both. A feed forward model of visual processing does not allow a stimulus displayed in a previous trial to effect the visual processing of a stimulus displayed in a new trial. In other words, if two stimuli share exactly the same features across all stimulus dimensions (i.e. size, orientation, brightness, etc.), then exactly the same amount of information will be available about both stimuli in the iconic store. In experiment 1 there was no difference in the feature level information about the target in any given trial of any of the three response conditions. This means that the iconic information available about the target for decision making should be exactly the same in any given trial of any of the three response conditions. A feed forward processing model does allow for previously displayed information to affect decision making or response level processing after the icon is formed. However, decision making and response level processing would affect either the time course of masking or the magnitude of masking, but not both.

According to a feed forward model, if the decision can be made faster in one response condition than it can in another other (e.g. due to a larger number of possible conclusions), then the icon will have less time to degrade before the decision is made, leading to higher response accuracy scores in that condition. This may explain the difference in the magnitude of response accuracy scores between the 2AFC and the 4AFC condition, but it does not explain the difference in the temporal pattern of masking in the RC response condition as compared to the 2AFC and 4AFC response conditions. A faster decision should be observed as a change on the temporal pattern of masking as well as the magnitude of masking (as observed in the RC response condition), so masking should level out earlier in the 2AFC response condition as compared to the 4AFC response condition. In other words, the temporal pattern of masking in the 2AFC response condition should look more like temporal pattern of masking observed in the RC response condition. Instead, a shift in the temporal pattern of masking is observed only in the RC condition. If faster decision making does explain the difference in the magnitude of masking between the 2AFC and 4AFC response conditions under a feed forward processing model, then there is no mechanism left to explain the shift in the temporal pattern of masking observed in the RC response condition.

A feed forward processing theory can explain the shift in the temporal pattern of masking observed in the RC response conditions through faster decision making. However, if faster decision making leads to a shift in the temporal course of masking under a feed forward processing model, then there is no mechanism left to explain the difference in the magnitude of masking observed between the 2AFC and 4AFC response conditions.

Speed of Decision Making

The speed of decision making does not appear to be related to the number of possible conclusions that can be made about the target. The set of possible targets in any give trial in the RC response condition was the same as set of possible targets in any give trial in the 4AFC response condition. The same number of decisions can be reached about the target in any given trial of both conditions, so the difference in the temporal course of masking observed in the RC response condition must be related to some other processing mechanism. The number of possible response also appears to be independent of the speed of decision making. The number of possible responses to the target in the RC response condition was the same as the number of possible responses to the target in the 2AFC response condition. The temporal pattern of masking was different between these two response conditions, indicating that the difference in the temporal pattern of masking observed in the RC response condition must be related to some other processing mechanism. Further, there were fewer possible responses in the 2AFC response condition as compared to the 4AFC response condition. If fewer possible responses lead to faster decision making, then this difference should be reflected as a difference in the temporal pattern of masking between these two response conditions.

It is likely that changes in the speed of decision making reflect changes in decision making processes. Because the speed of decision making decision making was the same in both the 2AFC and the 4AFC response conditions was the same, it is likely that the same decision making processes were being used by participants in both conditions. Because a feed forward processing theory would predict that the amount of information about the target available in iconic memory at and given time would be the same in both the 2AFC and 4AFC response conditions, and because participants were likely using the same decision making processes in both response conditions, the decision made about the target in either response condition should be equally as accurate, meaning that there should be no difference in the response accuracy scores between these two response condition. Masking levels off earlier in the RC response condition as compared to the other two response conditions because a change in decision making processes in the RC response allowed for faster decision making. However, this change in decision making did not lead to a more accurate decision. The magnitude of the response accuracy scores in the RC condition was the same as those in the 4AFC condition, indicating that the same amount of information was available about the target in both conditions when a decision was made. If a change in decision making leads to faster decisions, but not more accurate decisions, then there is no mechanism to explain the difference in the magnitude of masking in the 2AFC response condition as compared to the 4AFC response condition using a predominantly feed forward approach to visual information processing.

Experiment 2

Stimuli and Apparatus

The same apparatus was used in experiment 2 as were used in experiment 1. The four dot mask was the same as was used in experiment 1. A Pilot study reviled that the diamond stimulus used in experiment 1 yielded base line performance (i.e. response accuracy scores at a 0ms SOA) in the 2AFC response condition that was near chance when spatial attention was divided, so a different target stimulus was used. The target stimulus used in experiment 2 was a "C" object (figure 4b.), similar to the target stimulus use by Di Lollo, et al., (2000). The target had the same radius (measured form the outer edge) as the target in experiment 1 and the size of the gap was one half the radius of the target. The thickness of the target was approximately 0.1146 degrees of visual angle (3 pixels). For all three response conditions the center of the target, as well as any distracter targets, were positioned 3 degrees of visual angle from the center of the screen. The targets, when present, were exactly the same as the actual target except that the location of the gap was random for each target objects displayed. The fixation target in experiment 2 was a small plus sign "+" displayed at the center of the screen.

Procedure

The procedures used in experiment 2 were exactly the same as those used in experiment 1, except for the changes in described below. The same three response conditions – 2AFC, 4AFC and RC – used in experiment 2 were used in experiment 1, with each participant performing only one of the three response conditions. Participants in each response condition responded according to the location of the gap in the target object exactly as described in experiment 1. The target and mask durations were also the same as those used in experiment 1.

Only the four dot mask was used in experiment 2. Each response condition was again divided into four blocks of trials. In the T1 trial block, a single target mask pair was displayed at one of eight random locations on the screen. In the T2 trial block, the target mask pair was displayed at one of eight random locations and a second distracter target was displayed randomly in one of the seven remaining locations on the screen. In the T4 trial block, the target mask pair appeared in one of eight random locations and three distracter targets appeared at three of the remaining random locations. In the T8 condition, the target mask pair appeared at one of eight random locations while a distracter target appeared in all seven of the remaining locations.

Each experiment began with 28 practice trials in which a single unmasked target appeared in one of eight random locations. Each participant then performed a 28 trial practice block of the T1 display condition in order become familiar with the task and the display procedures. They then performed the T1 experimental block. After this first experimental block participants were given a short break, as was done between the experimental blocks in experiment 1. The order of the presentation the remaining blocks were then counterbalanced by participant with a practice block immediately preceding each of the experimental blocks. Breaks were given between experimental blocks, following the same procedures used in experiment 2, but no break was given between the practice blocks and the experimental blocks. The practice blocks consisted of 28 trials for each block. The experimental block consisted of 280 trials in each block. In each of the experimental blocks the target appeared five times in each of the eight locations for each of the seven mask durations. The location of the gap was random for every trial. Each participant contributed 40 trials at each mask duration in each response condition. Across all participants 720 trials per mask duration for each response condition were included in the analysis.

Participants

18 participants participated in each of the response conditions. In the 4AFC condition participants were age 18 to 21 (M = 19.39) and consisted of 7 males and 11 females. In the 2AFC condition participants were age 18 to 20 (M = 18.76) and consisted of 8 males and 10 females. In the RC condition participants were age 18 to 21 (M = 18.78) and consisted of 11 males and 7 females.

All participants had normal or corrected to normal vision as determined by self report and three visual acuity tests including contrast sensitivity, near acuity and far acuity measures. Participants were selected from the University of Kansas psychology research participation pool and received class credit for their participation.

Results

The data was analyzed using a 4 (number of distracters) X 7 (mask duration) X 3 (response condition) Mixed Linier Model. All main effects and all interactions were significant. For Mask Duration: $F_{(6,306)} = 284.07$, $p < .0001$. For number of distracter targets: $F_{(1,153)} = 1104.03$, $p < .0001$. For Response Condition: $F_{(2,51)} = 312.41$, $p < .0001$. For mask duration X Number of distracters: $F_{(18,918)} = 30.59$, $p < .0001$. For mask duration X condition: $F_{(12,306)} = 10.16$, $p < .0001$. For number of distracters X condition: $F_{(6,153)} = 17.85$, $p < .0001$. For Mask Duration X Mask Type X Condition: $F_{(36,918)} = 1.43$, $p = .0494$.

Post-hock tests for pair wise comparisons between cell means were performed using a Tukey's adjustment procedure. Figure 8 shows the mean response accuracy score for participants in each response condition, at each mask duration. Figure 8a shows the response accuracy in the T1 display condition. Figure 8b shows the response accuracy in the T2 display condition. Figure 8c shows the response accuracy in the T4 display condition. Figure 8d shows the response accuracy in the T8 display condition.

T1 condition

Using response accuracy for the 0ms mask duration as a baseline for comparison, no significant masking was observed in any response conditions for the T1 display condition.

T2 condition

Significant masking was observed in the 4AFC and the RC response condition for mask durations of 106ms and longer ($p < .05$), and marginally significant masking was seen the 2AFC condition. The p-value for the adjusted difference of the least squared means of the response accuracy scores between the 0ms mask duration and the 153ms mask duration in the 2AFC response condition was $p = .0607$. Accuracy was significantly higher in the 2AFC response conditions compared to the 4AFC response condition for all mask durations of 106ms and longer ($P < .05$). Accuracy was significantly higher in the RC response condition compared to the 4AFC response condition for mask durations of 200ms ($P = .0269$) and 247ms ($P < .0001$). There was no significant in difference accuracy between the 2AFC response condition and the RC response condition for any mask durations.

T4 condition

Significant masking was seen in all response conditions in the T4 display condition for mask durations of 47ms and longer ($P < .05$). There was no significant difference in accuracy between the 2AFC and RC conditions for any mask duration. Accuracy was significantly higher in the 2AFC response condition compared to the 4AFC response condition for mask durations of 106ms and longer ($P < .05$). Accuracy was significantly higher in the RC response condition compared to the 4AFC response condition for mask durations of 106ms, 200ms, and 247ms ($P < .05$). For a mask duration of 153ms, accuracy in the RC condition was only marginally higher compared to the 4AFC condition ($P = .0749$).

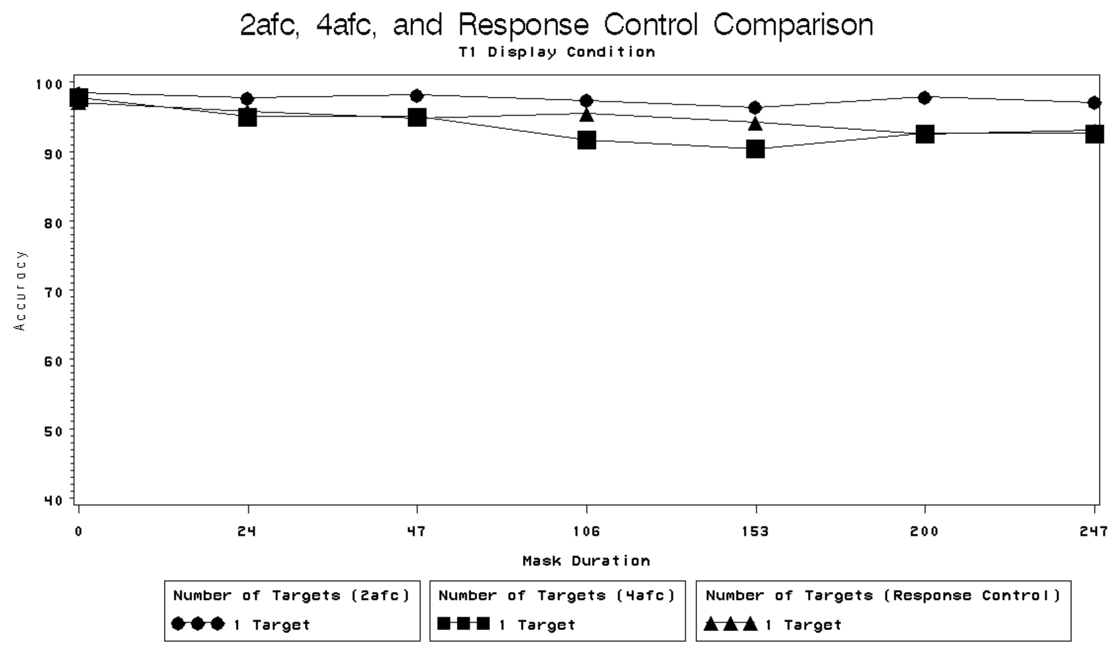
In experiment 1 there were two independent display conditions, each divided into two experimental blocks. In experiment 2 there were four independent experimental blocks, but each participant performed about the same number of trials in each experimental block as a participant in experiment 1. This means that a participant in experiment 2 only performed about half the number of trial in any given display condition as a participant in experiment 1. More participants were used in each response condition in experiment 2, but this still resulted in fewer observations per cell in the final analysis. This led to less power in the analysis of the data in experiment 2 as compared to experiment 1. This reduction of power likely prevented the comparison between the RC response condition and the 4AFC response condition at the 153ms mask duration from reaching significance.

T8 condition

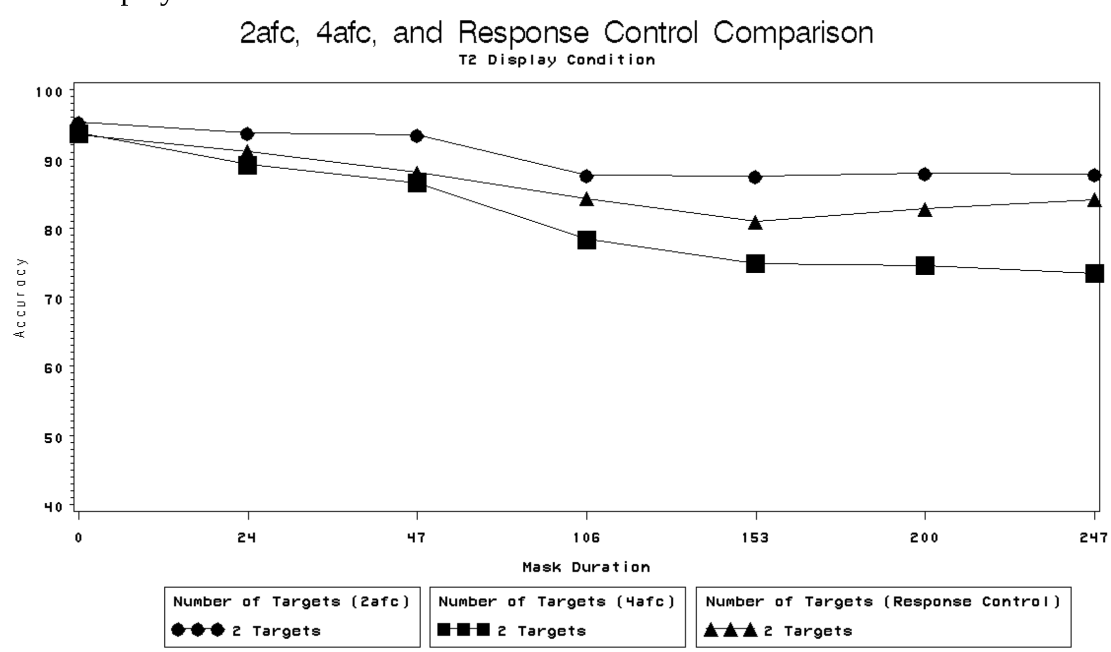
Significant masking was seen in the 2AFC and 4AFC response conditions for mask durations of 106ms and longer ($P < .05$). Significant masking was seen in the RC response condition for mask durations of 47ms and longer ($P \leq .0001$). Accuracy in the was significantly higher in the 2AFC condition compared to the 4AFC condition for all mask durations ($P < .05$) except the 24ms mask duration ($P = .6294$). There was no significant difference in accuracy between the RC and the 2AFC response conditions for any mask duration. Masking in the RC response condition was significantly higher compared to the 4AFC response condition for mask durations of 106ms and longer ($P \leq .0001$).

Figure 5:

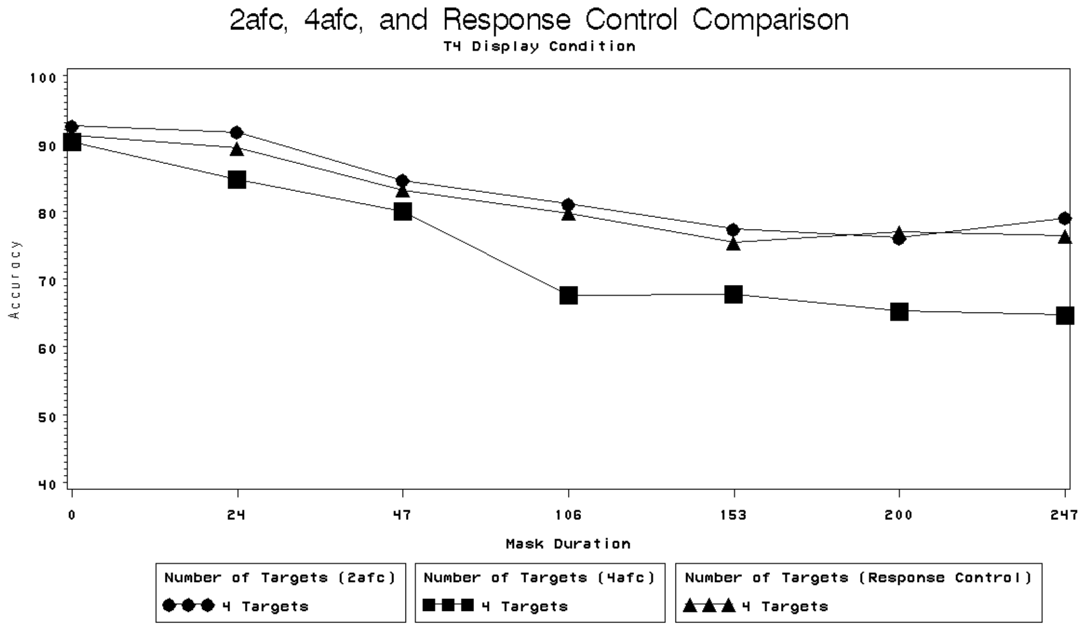
a. T1 Display condition



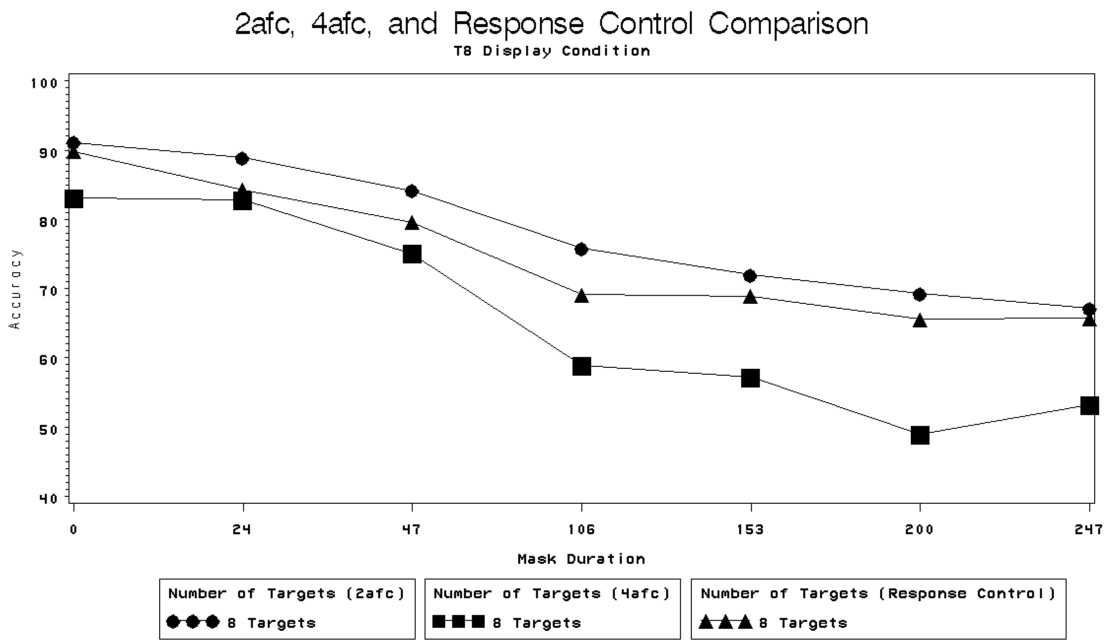
b. T2 Display Condition



c. T4 Display Condition



d. T8 Display Condition



Discussion

Object substitution masking is known to be modulated by spatial attention (Di Lollo, et al., 2000). The purpose of experiment 2 was to determine if the priming affect observed in experiment 1 are also modulated by spatial attention. The same three response conditions used in experiment 1 were implemented in experiment 2. Because different target stimuli were used in experiment 2, the results of experiment 2 can not be directly compared to those in experiment 1. However, the pattern of masking (i.e. the differences in the magnitude and temporal patterns of masking between the three response conditions) observed in experiment 2 can be compared to the pattern of masking observed in experiment 1.

The pattern of masking observed in experiment 2 is different than the pattern of masking observed in experiment 1. In experiment 1 the magnitude of the response accuracy scores in the RC response condition were the same as those in the 4AFC response condition, with response accuracy scores in the 2AFC response condition being significantly higher. This indicated that more information about the target was available when a decision about the target was made in the 2AFC response conditions than in the other two conditions, and that about the same amount of information about the target was available when a decision about the target was made in the RC response condition as was available when a decision about the target was made in the 4AFC response condition. These results indicated that priming of local loop information allowed more information about the target to be available for decision making in the 2AFC response condition.

In experiment 2 the relationship between the magnitude of the response accuracy scores between the RC response condition and the other two response conditions were reversed as compared to what was observed in experiment 1. The magnitude of the response accuracy scores were the same in the 2AFC and RC response conditions, and where higher that those in the 4AFC response condition. This indicates that about the same amount of information about the target was available when a decision about the target was made in the 2AFC response condition as was available when a decision about the target was made in the RC response condition. If a long term perceptual hypothesis was priming P-area activations, then the magnitude of the response accuracy scores in the RC response condition should have been lower that those observed in the 2AFC response condition. The absence of a difference in the response accuracy scores between the RC and 2AFC response conditions indicated that the priming of local loop information observed in experiment 1 was absent from experiment 2. These results indicate that, like object substitution masking, priming of local loop information is modulated be spatial attention.

P-area Priming Under Divided Spatial Attention

The object substitution model describes P-area patterns as being retinotopically organized (Di Lollo, et al., 2000). That is, any given P-area activation is specific to one particular location with in the visual field. P-area patterns have small receptive fields, meaning that a particular P-area pattern will not be activated unless the information in the input layer is at the corresponding location within the visual field.

Object level pattern information has even larger receptive fields, so that the same object level pattern can be activated by P-area pattern activations occurring at almost any retinotopic location. In other words a diamond displayed on the right side of a fixation target will activate the same object level pattern as a diamond displayed on the left side of a fixation target. However, in order of an object level pattern to prime P-area activations, the specific retinotopic location of the-to-be-primed P-area patterns must first be selected. If a specific retinotopic location is not selected, then all P-area patterns that are consistent with the object level pattern will be primed at all retinotopic locations. This would result in extensive overlap of primed P-area patterns at any given retinotopic location, which would eliminate any benefit that priming P-area patterns may have on the processing of new visual information.

In experiment 1 the spatial location of the target object was always known prior to its display, so the correct P-area patterns could be primed at the correct retinotopic location. However, in experiment 2 the spatial location of the target was never known prior to the display of the target. This makes the priming of P-area patterns at the correct retinotopic location impossible.

Response Accuracy Under Divided Spatial Attention

The four display conditions in experiment 2 where designed to divide spatial attention by an amount proportionate to the number of distracter targets present in the display. In order to identify the target in the display a participant must first identify the spatial location of the to-be-reported target. In order to locate the to-be-reported target in the any of the display conditions in experiment 2, except for the T1 display, a participant must first identify the spatial location the mask. In order to locate the mask a participant must process all of the elements in the display until the information at the target location can be identified as being different form the information at all other locations in the display. Because there is no information at any other location of the display in the T1 condition, the information at the target location does not have to be separated form any other information in the display, so it requires relatively little time to locate the target information. However, if there is more than one target on the screen, the information at all spatial locations at which any object is displayed must be processed to the point that the participant can separate the target location form the information at the other spatial locations in the display. Increasing the number of distracter targets in the display increases the time required to locate and begin processing the information about the target with the exclusion of all other information in the display (i.e. the time to contact).

The relationship between the number of distracters in the display and the amount of information about the target that is available when a decision about the target is made is reflected in the response accuracy scores in the four display conditions of experiment 2. Response accuracy scores in all three response conditions fall as the number of distracter targets in the display increase, and the pattern of masking in all three response conditions are stable across all four display conditions. However, unlike the results observed in experiment 1, no difference in the temporal pattern of masking between any of the response conditions was observed in experiment 2. This indicates that dividing spatial attention affected the amount of information that was available about the target when a decision was made, but not how long it took to make the decision.

Decision Making Under Divided Spatial Attention

Lower response accuracy scores in the 4AFC response condition compared to those in the other two conditions indicate the final decision about the target in the 4AFC response condition was less accurate than the final decision about the target in the other two response conditions. Because the magnitude of the response accuracy scores in the RC condition did not match those in the 4AFC condition, even thought the physical display was the same, it appears that the amount of information available about the target was not the determining factor of the accuracy of the final decision about the target. This means that the discrepancy in the magnitude of the response accuracy scores between the 2AFC and 4AFC response conditions are also likely not explained by a difference in the amount of information available about the target. The only remaining explanation involves the way in which decisions were being made about the information available about the target.

The exact decision criteria used by participants in any of the response conditions in either experiment in this study is impossible to determine, but a comparison between the pattern of masking observed in experiment 2 with the pattern of masking observed in experiment 1 may offer some clues about the response criteria used. In experiment 1, response accuracy scores in the RC condition leveled off at shorter mask durations compared to the other two response conditions. One possible reason that participants in the RC condition of experiment 1 could make faster decisions about the target is that they were making decisions based on less complete pattern information, while participants in the other response conditions waited until more complete pattern information became available.

As more complete pattern information about a target object becomes available with continued processing, different strategies can be used to make decisions about the object depending of the amount of information needed to make the decision. In experiment 2, the experimental task in each of the response conditions was to locate the gap in the target. The experimental task in experiment 1 was functionally equivalent. The only information needed to make a decision about the location of the gap in experiment 2 is the information about the location of the gap relative to the other possible locations of the gap. The rest of the information about the target is irrelevant. In the 2AFC response condition the top and bottom portion of the target could be eliminated as possible locations of the gap. This could allow a participant in this condition to simply divide the target in half. If the gap was located in one half of the target, then it could not be in the other half. If the gap was not located in one half of the target then it must be located in the other half. In other words participants in the 2AFC response condition only need the information at one location in order to make an accurate decision. Even if the pattern level information about the target was unclear or incomplete a decision could still be made because only the pattern of information about one half of the target was needed in order to make an accurate decision.

Participants in the 4AFC condition however, had to compare the information at one location to the information at three other locations. This means that none of the four locations could be eliminated as a possible location of the gap unless the information about at least three locations was available. This means that if the object level information about the target was unclear, or incomplete, then an accurate decision about the location of the gap was much more difficult.

The experiment instructions of in the RC response condition in experiment 2 may have allowed those participants to make decisions about the target in a very similar way to participants in the 2AFC response condition in experiment 2. Only two possible responses were required in the RC response condition. This means that the exact location of the gap relative to all four possible locations may not be necessary. As was possible for participants in the 2AFC response condition, participants in the RC response condition may have been able to divide the target in half and simply report which half of the target contained the gape. The distinction between a gap located at the top portion or the left portion of the target is not required to make an accurate decision about the target. Participants only needed to know that the gap was located somewhere in that half of the target. Once the presence or absence of the feature in one half of the target is established, an accurate decision can be made. This decision strategy is likely to produce more accurate responses compared to those in the 4AFC condition, which would explain why response accuracy scores in the RC response condition were higher that those in the 4AFC response condition. However, when used in the RC response condition this decision making strategy is likely more prone to errors as compared to the same strategy if used in the 2AFC response condition, which may account for the consistently (but not significantly) lower response accuracy scores in the RC conditions as compared to the 2AFC condition. One possible source of error is that a participant in the RC response condition is likely to divide the target so that one half encompasses the top and left portions of the target and the other half encompasses the right and bottom portions of the target. However, if an error is made in dividing the target and the gap is located, for example, at the bottom of the target, then it is possible for a participant to incorrectly identify the gap as being located in the top right half of the target rather then the bottom left half, which would lead to an incorrect response.

It is interesting that participants were able to use decision making strategies to improve response accuracy scores in experiment 2, but not in experiment 1. The answer to this discrepancy likely lies in a difference in the decision criteria used be participants in the two experiments. A decision about a target object is based on an object level representation of the target, but and object level representation does not have to be categorical, or even complete. In other words we don't need to know exactly what an object is, or if it is different form any other possible objects in order to make certain decisions about the object. However, an experimental task may bias a participant towards using more complete pattern information about a target object for decision making. This is likely a likely scenario in the 2AFC and 4AFC response conditions in experiment 1. The experimental task in these two conditions implies that the task is to identify and then report the identity of the target. However, the experimental task in the RC response condition allows for less precise decision criteria. Here, participants do not have to report the identity of the target. They only need to report the orientation of the target, which may not require as much information if they shift their decision criteria away from more complete pattern information and towards the use of less complete information. This would allow participants in the RC condition to make decision earlier. However, because of the presence of effective priming of P-area pattern information, less information about the target was available at any point in processing in the RC response condition as compared to the 2AFC response condition. Instead, the amount of information available about the target in the RC response condition was the same as the amount of information available about the target in the 4AFC response condition, so the accuracy of the final decision was the same in both response conditions. Only the time course of decision making was different.

The temporal pattern of masking was the same for all three response conditions in the experiment 2. This indicates that participants in this experiment were using the same decision making criteria in all three response conditions in this experiment. The absence of priming means that same amount of information was available for decision making at any given time in all three response conditions. It is impossible to know exactly how much information was available for decision making (i.e. how complete the pattern information was at the time of decision making) in experiment 2 as compared to experiment 1 because dividing spatial attention may slow down the processing of all levels of pattern information. However, decision criteria can be separated from response criteria.

To return to the snapshot metaphor, decision criteria will determine when the picture is taken. The amount of information about the target contained in the picture is determined by local loop processing factors (e.g. the amount of P-area priming, amount of interaction between the features of the target and the features of the mask, etc.). Response criteria will determine the accuracy of the decision, depending on the amount of information available in the picture. The response criteria describes the strategies used to make a response about the information in the picture. Changes in a participant’s response criteria can allow for accurate decision making, even if less clear or less complete pattern information is available due to changes in decision criteria. The term decision criteria is used because it refers to the perceptual level decision made about the target information (i.e. the activated high level pattern information). The term response criteria is used because it refers to the strategies used to make a response based on the information available.

The difference between the temporal pattern of masking seen in experiment 1 are caused by changes in the decision criteria used by participants in the RC response condition as compared to participants in the other two response conditions. The difference in the magnitude of masking between the 2AFC can 4AFC response conditions was due to the priming of local loop information, which led to a clearer “snapshot” of the information about the target at any given point in processing. The difference in the magnitude of masking the 4AFC response condition compared to the other two response conditions was observed in experiment 2 because changes in response criteria allowed participants in the RC response condition to make more accurate decisions than participants in the 4AFC response condition. No difference in the temporal pattern of masking between the response conditions was observed because the same decision criteria was used in all three response conditions, and only changes in decision criteria will affect the temporal pattern of masking.

Conclusion

The purpose of experiment 1 was to determine if a long term perceptual hypothesis about a target object can affect lower level visual processing of a new target. The results of experiment 1 confirm that it is possible for higher level pattern information activated by the display of a particular stimulus (i.e. a long term perceptual hypothesis) to prime lower level pattern information that is consistent with the previously displayed stimulus. This was demonstrated by comparing response accuracy scores of participants in two different conditions.

In one condition, the 2AFC condition, lower level patterns consistent with two perceptual separate long term perceptual hypotheses were primed. In a second condition, the 4AFC condition, lower level patterns consistent with four separate long term perceptual hypotheses were primed. The increased number of long term perceptual hypotheses in the 4AFC condition, as compared to the 2AFC condition, led to an increase in the number of primed lower level patterns. This in turn led to more competition for activation among the primed local loop information in the 4AFC condition when a new target was displayed. This competition led to a reduction in the amount of information available about the target when a decision about the target was made. This reduction in the amount of information available about the target was observed as a reduction in the accuracy of the decision about the target in the 4AFC condition as compared to the 2AFC condition.

Experiment 1 also addressed the role of decision making in visual information processing. It appears that the amount of time needed to make a decision is determined by the decision criteria set by the individual participant prior to the display of a stimulus. The time course of decision making is reflected by the point at which masking levels off (i.e. the mask duration after which response accuracy scores no longer drop). The change in the experimental task in the RC response condition as compared to the 4AFC and 2AFC response conditions seemed to change the decision criteria set by the participants in experiment 1 so that they could make decisions faster. This is observed as an earlier level off of masking in the RC condition as compared to the 4AFC and 2AFC response conditions. However, because the accuracy scores in the RC condition were exactly the same as the accuracy scores in the 4AFC condition, in which the physical display was identical, it seems that the speed of the decision about the target did not affect the accuracy of the decision.

Experiment 2 was conducted to explore how the lower level priming mechanisms observed in experiment 1 function when spatial attention is divided. The results of experiment 2 also allow or further exploration of decision making in a visual masking experiment.

The results of experiment 2 indicate that the priming of lower level pattern information does not occur, or is ineffective when spatial attention is divided. In this experiment response accuracy scores in the RC look more like more like the 2AFC condition than the 4AFC condition. This is the reverse of the relationship between the response conditions observed in experiment 1. At first glance, this may appear to contradict the results of experiment 1, but with further consideration this finding is not particularly surprising. Lower level patterns are retinotopically organized. In order for a high level pattern to prime a corresponding low level pattern, it must prime the correct pattern at the correct retinotopic location. Under focused attention viewing conditions, as occurred in experiment 1, the location of the next target is always known, so the correct lower level patterns can be primed at the correct retinotopic location. However, in experiment 2 the spatial location of the target is never known in advance, so the correct pattern at the correct retinotopic location can not be primed.

The reversal of the relationship between response accuracy in the RC and the other two response conditions in experiment 2 revealed some further information about the mechanisms of the decision making processes. Because the temporal pattern of masking was the same in all three response conditions, it appears that participants used the same decision criteria in these two conditions. The magnitude of response accuracy scores in the 2AFC and RC response conditions were higher than those in the 4AFC condition because participants were able to use response criteria to increase the accuracy of their response in the RC and 2AFC response conditions, even though the amount of information about the target was the same in all three response conditions.

References

Alpern, M. (1953). Metacontrast. *Journal of the Optical Society of America, 43,* 648–657.

Bachmann, T., Luiga, I & Põder, E. (2005). Variations in backward masking with different masking stimuli: I. Local interaction versus attentional switch. *Perception. 34,* 131–137.

Bernstein, I. H., Proctor, J. D., Proctor, R. W., & Schurman, D. L. (1973). Metacontrast and brightness discrimination. *Perception & Psychophysics, 14,* 293–297.

Breitmeyer, B. G. (1984) Visual masking: An integrative approach. New York: Oxford University Press.

Breitmeyer, B. G., Ogumen, H. (2006) Visual masking: Time Slices Through Conscious and Unconscious Vision. New York: Oxford University Press.

Breitmeyer, B. G. & Ganz, L. (1976). Implications of sustained and transient channels for theories of visual pattern masking, saccadic suppression, and information processing. *Psychological Review, 83,* 1–36.

Breitmeyer, B. G., Öğmen, H., & Chen, J. (2004). Unconscious priming by color and form: Different processes and levels. *Consciousness & Cognition, 13,* 138-157.

Breitmeyer, B. G., Ro, T., Öğmen, H., & Todd, S (2007). Unconscious, stimulus-dependent priming and conscious, percept-dependent priming with chromatic stimuli. *Perception & Psychophysics, 69,* 550–557.

Crawford, B. H. (1947). Visual adaptation in relation to brief conditioning stimuli. *Proceedings of the Royal Society of London. Series B, Biological Sciences, 134,* 283–302.

Di Lollo, V., Enns, J. T., & Rensink, R. A. (2000). Competition for consciousness among visual events: The psychophysics of reentrant visual processes. *Journal of Experimental Psychology: General, 129,* 481–507.

Enns, J. T., & Di Lollo, V. (1997). Object-substitution: A new form of masking in unattended visual locations. *Psychological Science, 8,* 135–139.

Enns, J. T. (2004). Object substitution and its relation to other forms of visual masking. *Vision Research, 44,* 1321–1331.

Eriksen, C. W. & Collins, J. F. (1965). Reinterpretation of one form of backward and forward masking in visual perception. *Journal of Experimental Psychology, 70,* 343–351

Felleman, D. J. & Van Essen, D. C. (1991). Distributed hierarchical processing in primate visual cortex. *Cerebral Cortex, 1,* 1–47.

Fehrer, E., Smith, E. (1962). Effect of luminance ratio on masking. *Perceptual and Motor Skills, 14,* 243-253.

Grossberg, S. & Mingolla, E. (1985). Neural Dynamics of Form Perception: Boundry Completion, Illusory Figures, and Neon Color Spreading. *Psychological Review 92,* 173–211.

Hellige, J, Walsh, D., Lawrence, V. W., & Prasse, M. (1979) Figural relationship effects and mechanisms of visual masking. *Journal of Experimental Psychology: Human Perception and Performance, 5,* 88-100.

Houlihan, K. & Sekuler, R. W. (1968). Contour Interactions in Visual Masking. *Journal of Experimental Psychology, 77,* 281-285

Hubel D. H. & Wiesel T. N. (1962). Receptive fields, binocular interactions and functional architecture in the cat's visual cortex. *Journal of Physiology, 160,* 106–154.

Hubel D. H. & Wiesel T. N. (1965). Receptive fields and functional architecture in nonstriate areas (18 and 19) of the cat. *Journal of Neurophysiology, 28,* 229–289.

Hubel D. H. & Wiesel T. N. (1968). Receptive fields and functional architecture of monkey striate cortex. *The Journal of Physiology, 1,* 215–243.

Kahan, T. & Mathis, K. (2002). Gestalt grouping and common onset masking. *Perception & Psychophysics, 64,* 1248–12549.

Kahneman, D. (1968). Methods, findings and theories in studies of visual masking. *Psychological Bulletin, 70,* 404–425.

Kinsbourn, M. & Warrington, E. (1962). The effect of an after-coming random pattern on the perception of brief visual stimuli. *Quarterly Journal of Experimental Psychology, 14,* 223–234.

Kolers, P. A. (1962). Intensity and contour effects in visual masking. *Vision Research, 2,* 277–294.

Matsumura, M. (1976). Visual masking by luminance increments and decrement: effects of rise time and decay time. *Tohoku Psychologica Folia, 36,* 104–114.

Merikle, P. M. (1980). Selective metacontrast. *Canadian Journal of Psychology, 34*, 196–199.

Moore, C. M. & Lleras, A. (2005). On the Role of Object Representations in Substitution Masking. *Journal of Experimental Psychology: Human Perception and Performance, 31*, 1171–1180.

Ogmen, H., Breitmeyer, B. & Melvin, R. (2003). The what and where in visual masking. *Vision Research, 12*, 1337-1350.

Proctor, R. W., Nunn, M. B. & Pallos, I. (1983). The influence of metacontrast masking on detection and spatial-choice judgments: an apparent distinction between automatic and attentive response mechanisms. *Journal of Experimental Psychology: Human Perception and Performance, 9,* 278–287.

Reiss, J. E. & Hoffman, J. E. (2006). Object Substitution Masking Interferes With Semantic Processing Evidence From Event-Related Potentials. *Psychological Science, 17,* 1015–1020.

Reiss, J. E. & Hoffman, J. E. (2007). Disruption of early face recognition processes by object substitution masking. *Visual Cognition, 15,* 789–798.

Schiller, P. H. & Smith, M. C. (1966). Detection in metacontrast. *Journal of Experimental Psychology, 77,* 32-39.

Sperling, G. (1963). A model for visual memory tasks. *Human Factors, 5,* 19–31.

Sperling, G. (1965). Temporal and spatial visual masking. I. Making by impulse flashes. *Journal of the Optical Society of America, 55,* 541–559.

Treisman, A. M. & Gelade, G. (1980). A feature-integration theory of visual attention. *Cognitive Psychology, 12,* 97–136.

Turvey, M. T. (1973). On peripheral and central processing in vision: Inferences from an information-processing analysis of masking with patterned stimuli. *Psychological Review 80,* 1–52.

Weisstein, N. (1966). Backwards masking and models of perceptual processing. *Journal of Experimental Psychology, 72,* 232–240.