What's new in visual masking?

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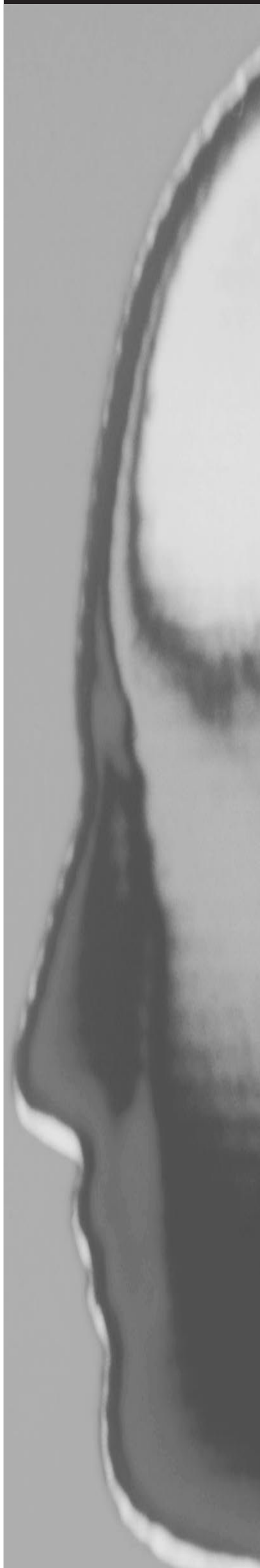
A brief display that is clearly visible when shown alone can be rendered invisible by the subsequent presentation of a second visual stimulus. Several recently described backward masking effects are not predicted by current theories of visual masking, including masking by four small dots that surround (but do not touch) a target object and masking by a surrounding object that remains on display after the target object has been turned off. A crucial factor in both of these effects is attention: almost no masking occurs if attention can be rapidly focused on the target, whereas powerful masking ensues if attention directed at the target is delayed. A new theory of visual masking, inspired by developments in neuroscience, can account for these effects, as well as more traditional masking effects. In addition, the new theory sheds light on related research, such as the attentional blink, inattentional blindness and change blindness.



Masking is a widely used and powerful way of studying visual processes. At the most general level, masking refers to a reduction in the visibility of an object (the target) caused by the presentation of a second object (the mask) nearby in space or time. In the spatial domain, merely surrounding the target with non-target items (an effect that is termed 'crowding'[1]) can reduce the visibility of a target. Inserting a temporal interval between the target and mask leads to more complex effects. For example, a target that is highly visible when presented briefly by itself can be rendered completely invisible by the subsequent presentation of a non-target object in the same (or nearby) spatial location. 'Backward masking' of this kind has its strongest influence not when target and mask objects are presented simultaneously, as intuition might suggest, but rather when a brief temporal gap is inserted between the presentation of the target and the mask. Such spatio-temporal interactions provide valuable insights into the mechanics of the visual system and provide information about the time required to form a percept[2], the spatial range of influence between objects[3] and visual processes that are beyond conscious awareness[4,5].

In this article, we summarize insights that have been gained in recent studies of visual masking. However, we first distinguish between two ways in which masking is used to study vision. On the one hand, masking is a convenient tool used by many researchers to regulate the difficulty of a task, so that accuracy falls into a measurable range. An informal survey of a recent volume of *Perception and Psychophysics* (Vol. 61, 1999) indicated that 14/93 (15%) of articles on vision used backward masking for the practical purpose of limiting visual access to the target over a controlled period of time. A second, smaller group of articles (5/93 or 5%) was concerned with the fine-grained spatial and temporal aspects of masking itself. It is important to note that although the present article might seem to be concerned primarily with the latter concept, our theory has equally important implications when masking is used as a tool of convenience.

The standard view

Visual masking is typically divided into two types, based on the spatial relationships that exist between the contours of the target and mask patterns. Masking that involves spatial superimposition of contours is commonly referred to as 'pattern masking', while masking that involves closely adjacent but nonoverlapping contours it is called 'metacontrast'. Typical examples of stimuli used in each of these types of masking are shown in Fig. 1a,b.

Pattern masking presents the visual system with two kinds of spatio-temporal conflict. One occurs when the target and mask are perceived as part of the same pattern as a consequence of imprecise temporal resolution by the visual system. In this case, masking is akin to the addition of spatial noise (the mask) to the signal (the target) at early levels of visual representation and is therefore referred to as 'integration masking'[3,6–8]. The temporal signature of this form of masking is approximate symmetry around a peak at a stimulus onset asynchrony (SOA, the interval between the presentation of the target and mask) of 0 ms, with a complete absence of masking beyond an SOA of about 100 ms in either direction.

A second conflict arises when processing of a first pattern (the target) is interrupted by a second pattern (the mask) that appears in the same spatial location before the target has been fully processed. This conflict does not

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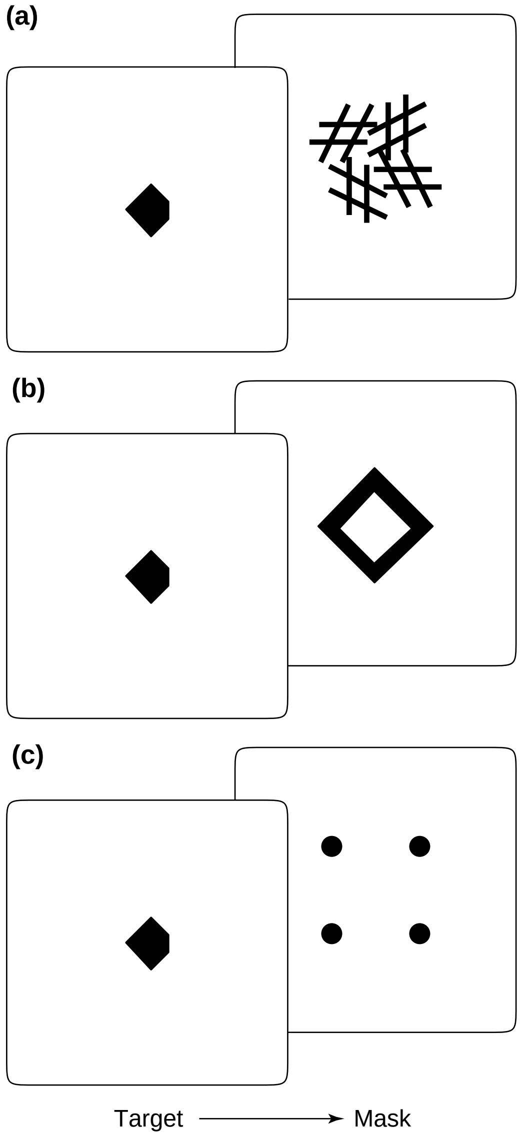

Fig. 1. Three different visual masks that might follow a briefly presented target shape in studies of visual backward masking. For the target depicted, observers attempt to identify which corner of a diamond has been erased. **(a)** Pattern mask: contours of the mask are spatially superimposed on the contours of the target. **(b)** Metacontrast: mask contours closely fit (but do not overlap) the target contours. **(c)** Four-dot mask: four small dots surround the target. There are no standard theories that predict that masking will occur with the four-dot mask.

involve the early stages of processing, where contours are defined, but instead involves a competition for higher-level mechanisms that are engaged in object recognition. It is referred to as 'interruption masking'[9]. The amount of time spent processing the target is sharply curtailed if a mask follows in rapid succession. The temporal characteristics of masking by interruption are very different from those of masking by integration. Interruption masking can occur only when the mask appears after the target. The masking function is referred to as U- or J-shaped, because target accuracy is often lowest at SOAs that are greater than zero and improve at longer SOAs (Refs 10,11).

In addition to their temporal characteristics, pattern-masking processes are distinguishable on the basis of physical attributes (which influence integration masking) and informational attributes (which influence interruption masking). For example, integration masking increases with the luminance contrast of the mask, whereas contrast has little (if any) effect on interruption masking[3,7,12]. Conversely, varying the number of potential targets between trials (i.e. manipulating set size) has little effect on integration masking, but markedly increases masking by interruption[12] (see Fig. 2).

Metacontrast masking occurs when masking shapes closely fit the contours of a target shape but do not touch them[3,13]. Importantly, when the interval between the presentation of the target and mask is either very short or very long, the target is clearly visible. At intermediate SOAs, however, perception of the target is impaired and leads to a U-shaped function of accuracy versus SOA. The mechanisms thought to be at work are inhibitory interactions between neurons that represent the contours of the target and the mask[3,14]. The main idea in such 'two-channel' theories is that the onset of each shape initiates neural activity in two channels; one fast-acting but short-lived, the other slower acting but longer lasting. The fast-acting channel transmits transient events that signal the stimulus onset and offset, whereas the slower channel transmits sustained signals regarding the stimulus shape and color. Metacontrast masking occurs when fast-acting signals in response to the mask inhibit the sustained activity generated by the earlier target. Figure 3 shows the typical time course of metacontrast masking[15].

A key piece of evidence consistent with metacontrast masking theories based on inhibitory contour interactions is the relationship between masking strength and contour proximity[3,16]. Masking is sharply reduced as the separation between target and masking contours is increased even by a fraction of a degree.

Nagging problems for the standard view

Although these standard views account for a large portion of the data on visual masking, there are several persistent findings that complicate the picture. First, consider the perceptual fate of masked targets. In the standard view, backward masking terminates the processing of the target at a precategorical level[7–9]. However, a phenomenon known as 'masked priming' suggests that processing of masked targets continues to lexical and even semantic levels. In conventional priming, where the prime word is not masked, a target is identified more easily if it is preceded by a semantically-related prime word[5,17]. In masked priming, the prime word is followed by a mask that prevents the observer from being able to report the target. However, the facilitation that is found in visible priming is also seen with masked priming[4,5]. This suggests that backward masking does not interrupt target processing at an early level, which is contrary to current theories. It is not the analysis of the target that is disrupted, but access to this analysis by conscious visual processes.

A second finding that is difficult to reconcile with the standard view is that there is little neurophysiological evidence that a backward mask suppresses the target signal. In studies of backward masking by pattern, visual components of the neural signal associated with the target (e.g. P1, N1, N400 components of the ERP) are indistinguishable under conditions in which behavioral masking does and does not occur[18,19]. A similar effect occurs with metacontrast masking[20–22]. These outcomes cast serious doubt on standard inhibition theories. The apparent inconsistency between behavioural and neurophysiological measures of masking can be resolved by replacing the idea of inhibitory interactions with that of cortical 'multiplexing'[20,23], with the same neurons participating in different computations at various stages in the processing of a visual display.

Finally, current theories do not accommodate the notion that attention plays a crucial role in visual masking. We mentioned earlier that one characteristic of integration masking that distinguishes it from interruption masking is differential sensitivity to attentional manipulations such as set size[12]. However, no interruption masking theories predict that increments in set size should result in larger masking effects. The same is true for metacontrast masking, the strength of which is modulated by: (1) the way in which observers subjectively organize an ambiguous display[24]; (2) the extent of practice[25]; (3) speed-accuracy criteria[26]; and (4) semantic relationships[27]. Clearly, all forms of masking await an account in which spatial attention plays an integral role in masking.

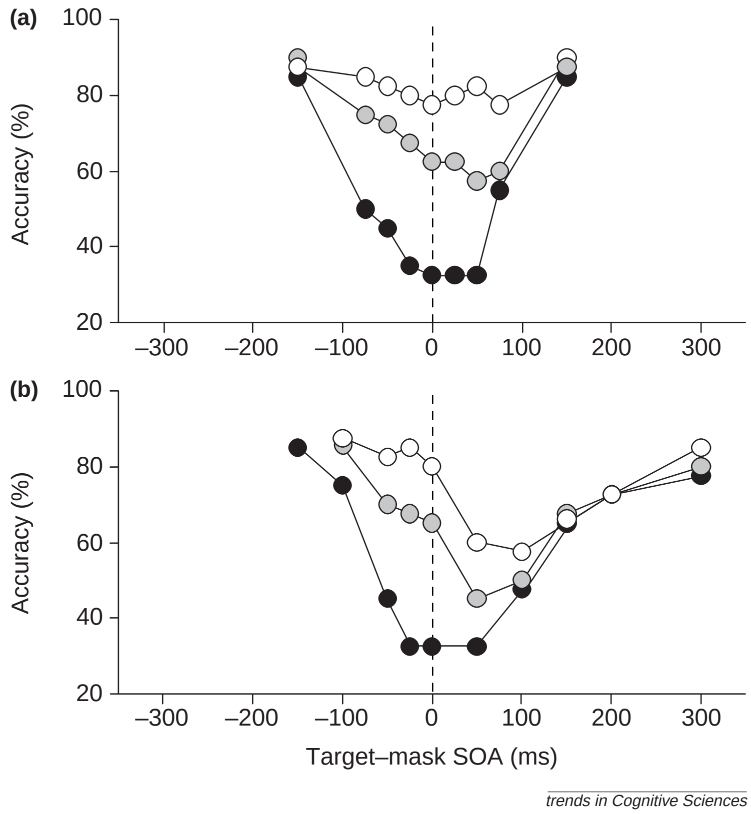

Fig. 2. Letter identification accuracy in a pattern masking experiment. A target letter is flashed briefly at one of 12 possible locations in a clock-face configuration. Three different levels of mask intensity (black symbols = high; gray symbols = medium; white symbols = low) were tested over a range of target–mask SOAs. Negative SOAs represent forward masking and positive SOAs backward masking. **(a)** Set of one letter. **(b)** Set of 12 letters. Mask intensity is most effective when mask and target are presented simultaneously (SOA = 0), whereas set size is most effective when SOA > 0 (backward masking). Abbreviation: SOA, stimulus onset asynchrony. (Adapted from Ref. 12.)

New forms of masking that defy the standard view

In our laboratory, we have been exploring two new forms of masking that are difficult to reconcile with current theories. Here, we provide only a brief introduction to give the reader a flavor of the phenomena that require explanation. These masking effects can be experienced first hand on the internet (http://www.interchange.ubc.ca/enzo/osdescr.htm) and can be read about elsewhere[15,28,29].

The first form of masking (Fig. 1c) occurs when a briefly presented target is followed by four dots that surround (but do not touch) the target shape[15]. Standard theories predict that no masking will occur in this case because the four dots constitute neither a superimposed pattern nor a surrounding contour. Nonetheless, strong masking does occur. Furthermore, four-dot masking is crucially dependent on the target not being the focus of attention. When attention can be focused on the target location before the target-mask sequence, no masking occurs.

The second form of masking is called 'common onset' because the target and mask come into view simultaneously[28]. No masking occurs if the target and mask disappear simultaneously, which indicates that the duration and contrast of the display items are sufficient to support perception. Masking does occur, however, if those parts of the initial configuration that belong to the target are deleted and only the mask continues to be displayed. Even a short postponement of mask deletion causes masking, the strength of which increases with the duration of visibility of the mask. This is a form of masking that is not predicted by the previously described mechanisms of integration (which incorrectly predicts maximum masking at a mask duration of 0 ms), interruption or metacontrast (which require the onset of a second pattern to interrupt processing of the first). Instead, the key factor appears to be that the mask remains visible following deletion of the target.

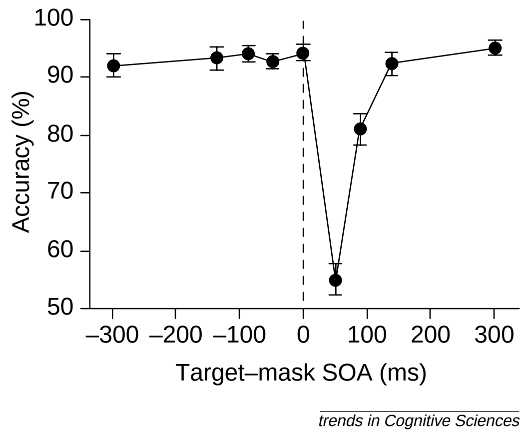

Fig. 3. Shape identification accuracy in a metacontrast masking experiment. A diamond shape was flashed briefly at the center of gaze while a surrounding mask appeared briefly over a range of target–mask SOAs. No forward (SOA < 0) or simultaneous (SOA = 0) masking occurred and backward masking was greatest at SOAs of 50–100 ms. Abbreviation: SOA, stimulus onset asynchrony. (Adapted from Ref. 15.)

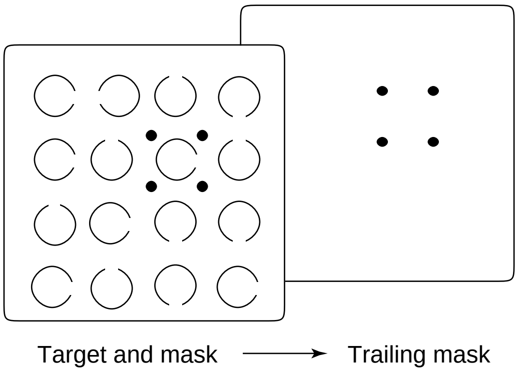

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Fig. 4. Illustration of the display sequence in a common-onset masking experiment involving a four-dot mask. The observer is required to indicate the orientation of the gap in a broken ring that is highlighted by four dots. The other broken rings served as distractors. In any given display, the number of broken rings varied from 1 (target with no distractors) to 16 (target with 15 distractors, illustrated). The sequence began with a combined display of the target, mask and distractors for 10 ms and continued with a display of the mask alone for a variable amount of time. (Adapted from Ref. 29.)

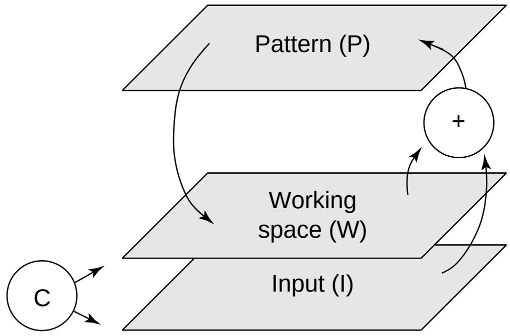

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Fig. 5. One module in the computational model for object substitution. The onset of a new visual event initiates activity in all layers on the first cycle. The activity in the pattern layer (P) is then fed back to the working space (W) by means of a simple overwriting operation. In this transfer, pattern information is translated back to the codes of the input layer (I), permitting a direct comparison (C). If the code in the pattern layer is to be successfully bound to its actual display location, the re-entrant signals need to be placed in spatial registration with the active signals in the input layer. Most important for masking is that the contents of the input layer change dynamically with new visual input. The contents of the pattern layer, by contrast, change more slowly because its input is a weighted sum of what is currently in the input layer and what was in the working space on the previous iteration. This produces a degree of inertia in the system's response to changes in input, which is an unavoidable consequence of re-entrant processing. If the visual input changes during this crucial period of inertia, masking will ensue. (Reproduced, with permission, from Ref. 29.)

These two new forms of masking were recently combined in a series of experiments in which an initial, brief display, consisting of several potential targets with four small dots surrounding one of them, was followed by a second display that contained only the four dots[29]. The observer's task was to report the target item highlighted by the four dots, as shown in Fig. 4. Little or no masking was observed when: (1) there was only one potential target; (2) the target differed from all other non-target items by a distinctive feature; or (3) the four dots preceded the target display by 90 ms. By contrast, pronounced masking occurred when: (1) many potential targets were displayed; (2) targets and non-targets were not easily distinguishable; and (3) no prior spatial cue was provided. These results suggest that common-onset masking by four dots is crucially dependent on the focus of spatial attention.

Masking based on cortical re-entrant processing

Our novel view of masking is based on recent advances in neuroscience and psychophysics. Our starting point was the principle that communication between two brain areas is never unidirectional: if a source area sends signals to a target area, then the target area sends signals back to the source area through re-entrant pathways[30–32]. It has been suggested that the architecture of cortical re-entry might be used to test for the presence of specific patterns in the incoming signals[33,34]. Specifically, it is thought that the circuit actively searches for a match between a descending code, representing a perceptual hypothesis, and an ongoing pattern of low-level activity. When such a match occurs, the neural ensemble is 'locked' onto the stimulus.

We incorporated these findings into a computational model of masking[29]. The central assumption in the model is that perception is based on the activity of modules, similar to that illustrated in Fig. 5, which are arrayed over the visual field. Each module is conceived as a circuit comprising connections between cortical area V1 and a topographically related region in an extrastriate visual area. The output of each module is a representation of the spatial pattern within its receptive field.

Based on the model in Fig. 5, perception of the input pattern emerges from iterative comparisons between the high-level codes and the ongoing low-level activity generated by the initial stimulus. For example, given a brief display in which the target and the mask are displayed simultaneously, target processing can be based on the visible persistence that follows the brief display. The fact that all parts of the display decay uniformly means that there is no imbalance in activity between mask and target pattern representations and observers are consequently able to identify the target accurately. Indeed, target identification accuracy was found to be high in this case, as shown in Fig. 6.

By contrast, masking occurs when there is a mismatch between the re-entrant signal and ongoing activity at a lower level. This occurs when the target items are deleted, leaving only the four-dot mask in the target location. The ongoing activity at the lower level would then consist of an image of the mask, maintained by continued sensory input, and a decaying image of the target. This creates a mismatch with the re-entrant perceptual hypothesis, which includes the target as well as the mask. Given this kind of conflict, what is perceived will depend on the number of iterations required to identify the target. If only a few iterations are required, conscious target identification might be completed before the target signal has faded completely. However, if more iterations are needed, a new perceptual hypothesis is formed that is consistent with the currently predominant low-level activity and the 'mask alone' percept replaces the 'target plus mask' percept. As shown in Fig. 6 and in the internet demonstrations, masking by four dots becomes stronger as a joint function of set size (delaying attention to the target location) and mask duration (increasing the likelihood of seeing the mask alone percept).

Two alternative interpretations should be considered and dismissed. It might be argued that the masking seen in Fig. 6 is caused by the abrupt termination of the mask. Such offset transients are known to influence the degree of metacontrast masking[35]. However, offset transients are not the primary influence in common-onset masking for two reasons. First, masking is very much in evidence at a mask duration of 320 ms, which is too long after the target presentation to be effective. Second, the offset-transient hypothesis predicts progressively weaker masking with increasing mask duration[35]. Instead, masking becomes progressively stronger and as such cannot be explained by offset transients alone.

It could also be argued that re-entrant processes are not really needed to explain common-onset masking. Perhaps it is the relatively long duration of the mask that causes attention to be drawn to it rather than to the shorter-lived target item at the same location. This hypothesis was ruled out by experiments in which the mask was shown for an even longer period, beginning before the onset of the target display and outlasting it[29]. Although this modification had the effects of both increasing the overall duration of the mask and focusing attention directly on it, masking was still sharply reduced. This indicates that it is the presence of the mask *after* the target that is critical, not its absolute duration relative to the target. We regard this as strong support for the important role played by re-entrant processes in perception.

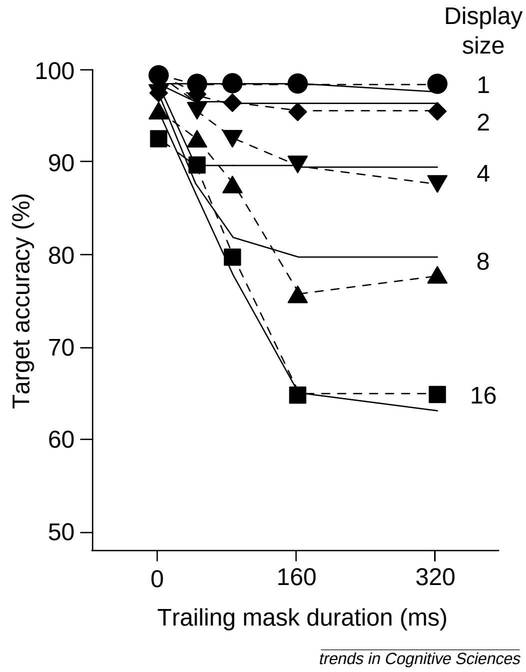

Fig. 6. Target identification accuracy in a common-onset masking experiment involving a four-dot mask. Symbols and dashed lines represent psychophysical data and the solid lines represent the quantitative predictions of the computational model for object substitution. No masking occurs when attention can be rapidly deployed to the target location, such as when set size is one. Accuracy is also not greatly affected by increments in set size, provided that the four-dot mask terminates with the target display (mask duration equal to zero). However, masking occurs when set size and mask duration increase. According to object-substitution theory, this is the result of the representation of the unattended target being replaced by the mask representation before target identification is complete. (Reproduced, with permission, from Ref. 29.)

The object-substitution model accounts naturally for the relationship between masking and spatial attention. Because the main mechanism involves successive iterations of re-entrant processing, every variable that increases the number of iterations required to identify a target will also increase the strength and the temporal course of backward masking. It is well established in the attention literature that conscious target identification is delayed by a wide spatial distribution or misdirection of attention[36,37]. This proposed role for attention in masking phenomena is also consistent with what is known about masked priming[4,5,18,19]. Although items outside the focus of attention might not be experienced consciously, they nonetheless are processed sufficiently to influence ongoing cognitive processes.

The object-substitution model also accounts for standard masking effects. Indeed, there is no difference in principle between masking with common onset and the broad characteristics of metacontrast and pattern masking. From this perspective, all forms of backward masking involve the perceptual substitution of a temporally leading target by a trailing mask, if the mask appears before target identification is complete. We might expect there to be minor differences that would be unique to each form of masking, especially at very short temporal intervals, where contour integration and interactions are most likely. For example, we have distinguished between classical metacontrast masking, which occurs early in processing and depends critically on the proximity of target and masking contours, and object-substitution masking, which occurs later and is unaffected by proximity of contours[29]. However, the crucial ingredient of object substitution that is shared by all forms of backward masking is that the mask is visible during the period in which the iterations between higher-level pattern and lower-level contour representations are likely to occur.

An important feature of object substitution is that it makes sense of several puzzling findings that cannot be resolved with the standard view of masking. First, it is now easier to understand why both pattern masking[12] and metacontrast[2], which were believed to be distinctly different mechanisms, produce similar effects when set size is varied. Specifically, very little masking occurs when the target is the only item on display, while pronounced masking of the same target occurs when it is only one of several items on display. The same is true for common-onset masking by four dots.

A second result that is readily explained by object substitution is the finding that a backward mask is more effective as the duration of the mask increases[29,38]. Neither the

Box 1. Visual masks influence perceptual processes

A good example of how the choice of mask alters the perceptual processes under investigation can be seen in recent research into the attentional blink. In these studies, the perception of the second of two briefly displayed targets is impaired if it is presented with a temporal lag (up to 500 ms) after the first target (Ref. a). For example, observers could be asked to report the identity of two letters inserted into a visual stream of digits, as shown in Fig. Ia. Although accuracy of reporting the first letter is nearly perfect, accuracy in identifying the second letter is substantially lower, as shown in Fig. Ib. This deficit has been attributed to the second target being unattended while processing resources are devoted to the first target. However, it has long been recognized that the second target must be masked for the attentional blink to occur. Ostensibly, the purpose of masking was to increase the difficulty of processing the second target, thereby bringing accuracy within a measurable range. However, if this is the principal function served by masking, masking by integration and interruption should be the same, with the second target deficit occurring in both procedures.

In fact, the lag-dependent second target accuracy deficit occurs in this task only if backward masking is used (Refs b,c). If a simultaneous mask is used, identification of the second target is impaired equally across all time lags (Fig. Ic). This suggests that object substitution is the mechanism that accounts for masking in the attentional blink. That is, while unattended, the second target is vulnerable to replacement by the trailing mask. As a consequence of this replacement, the mask is substituted for the second target as the object for eventual conscious registration. This clearly demonstrates that backward masking of the second target is not simply a methodological convenience, but in fact reveals the functional mechanisms that are involved in masking, which would have gone undetected had masking been used merely as a tool.

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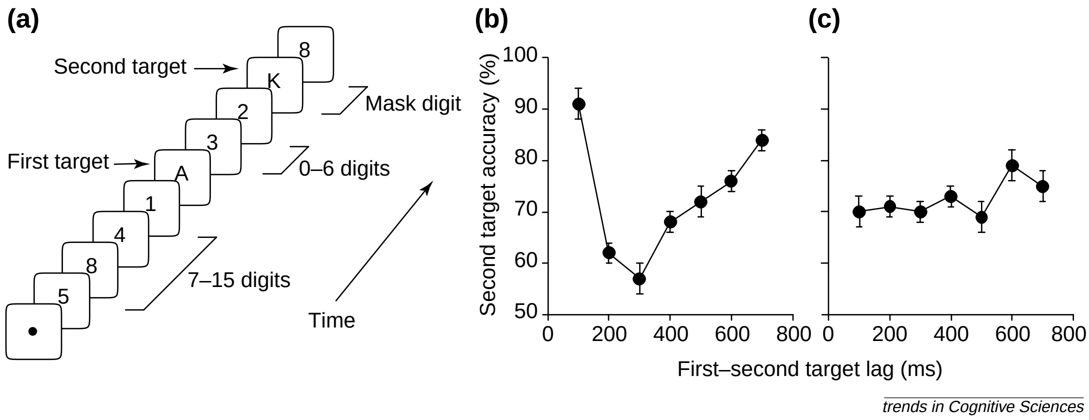

Fig. I. Illustration of the display sequence in the attentional blink paradigm (a). Second-target accuracy is shown as a function of lag from the first target when **(b)** a pattern mask follows the second target and **(c)** a pattern mask is presented simultaneously with the second target.

standard view of interruption masking (based on the termination of target processing) nor that of metacontrast (based on channel inhibition) predicts that the influence of a mask will increase with its duration. Object substitution, however, makes precisely this prediction, because a mask of longer duration will be more likely to complete and reinforce the iterative pattern-confirmation process.

Third, object substitution predicts that a mask will not simply terminate target processing, but that the mask itself will become the new focus of object identification mechanisms. This prediction has been observed in studies of visual masking in rapid serial visual presentations (Ref. 39, and J. Martin *et al.*, unpublished; see also Box 1, Fig. I). When observers fail to report the identity of a masked target, they usually report the item that has followed (and therefore masked) the target. This effect is seldom seen in traditional studies of masking because observers are rarely asked to report directly on their perception of the mask. Nevertheless, shape priming in a study of metacontrast masking suggests that this phenomenon also occurs in traditional studies of masking[40].

Finally, object substitution can explain the large imbalance between forward and backward effects, both in standard masking[3,12] and masking by common onset[29]. As stated above, forward masking has a very narrow temporal window and is fully accounted for by the inherent temporal 'smearing' of the visual system, which reduces it to the mechanisms of masking by spatial crowding and noise integration. Backward masking, by contrast, has a much wider temporal window and is often much larger in magnitude. As we noted above, both of these characteristics can be exaggerated easily by manipulating the set size and similarity of the target and mask. The large bias that favors the effectiveness of backward masking is exactly what is predicted if the primary mechanism involves the replacement of an emerging object representation with another, because the initial representation has been contradicted by subsequent input.

Object substitution and the role of attention in perception

One of the most important practical implications to arise from our understanding of object substitution is that backward masking does not simply terminate the processing of a target. Rather, the perceptual mechanisms of conscious perception appear to be actively engaged in perceiving the mask. An example of this principle is illustrated in Box 1 for a phenomenon known as 'the attentional blink'.

We believe that masking by object substitution also has direct relevance to the recently popularized phenomena of 'inattentional blindness' and 'change blindness'. Inattentional blindness refers to the phenomenon wherein objects that are presented to the visual system are not seen because the observer is attending to something else[41]. One of the key details of the induction procedure that is rarely given much consideration is the role played by a pattern mask, which is presented immediately following the display. Usually, the mask is used to prevent additional processing of the display after it is removed from the screen. However, object substitution predicts that perception of the mask directly interferes with access to briefly presented and unattended targets. More specifically, object substitution predicts that inattentional blindness will increase directly with mask duration, even if the mask consists of four surrounding dots that would otherwise not interfere with target perception.

Change blindness refers to the finding that large changes to the visual world go undetected if attention is not already focused on the objects or area in which the change occurs[42–46]. There have been few systematic studies of the role played by the visual image that replaces the retinal (or environmental) location of the original image. Yet, from the perspective of object substitution, such an image would seem to play an important role because it prevents access to the fading representation of the original image and replaces it in consciousness.

In conclusion, it is important to emphasize the distinction between masking as a tool of convenience and as a tool for probing underlying perceptual mechanisms. For example, in the attentional blink, inattentional blindness and change blindness, we have established that a backward visual mask is a crucial factor in the failure to 'see' objects that are clearly registered on the retina. Nevertheless, it is important to note that the mechanisms under investigation are not inherently tied to backward masking; masking simply makes them more readily apparent. In support of this view, recent reports in each of the above-mentioned areas have showed that failures of perception can be induced in the absence of a mask. Specifically, (1) an attentional blink occurs without masking if the nature of the task is sufficiently different for the first and second targets[47]; (2) inattentional blindness occurs when no mask follows the target, although the rate is much reduced[41]; and (3) change blindness can be induced simply by splashing 'mud' unexpectedly onto parts of a picture other than the target[48]. Importantly, in accordance with object-substitution theory, each of these manipulations involves directing attention away from the visual target, which will then go undetected. Specifically, while attention is either focused on the task of identifying an initial target or 'captured' by unexpected events (such as mudsplashes), before attention can be redeployed to the visual target, the iterative processes of conscious perception would have lost trace of the crucial target or any changes that might have occurred.

Outstanding questions

- What is the true relationship between focused spatial attention and early visual processing? The computational model for object substitution assumes that early visual processes operate somewhat independently of the focus of attention. The limiting factor is the length of time that elapses before attentional mechanisms interact with the early processes in a given location. However, is it possible that the mechanisms of attention themselves alter the operations of these early processes? What are experimental techniques that would help decide between these alternatives?
- Does masking by object substitution occur if shapes are equiluminant with the background? Previous studies have reported evidence for two separable components of backward masking effects in both pattern masking and metacontrast masking, with only the earlier components being sensitive to luminance in each case. Because masking by object substitution is thought to occur later in processing and to be independent of luminance transients, it should occur unabated with equiluminant displays, although the earlier components of masking might no longer occur with these displays.
- Does common-onset masking interfere with the perception of some or all aspects of a target? For example, many iterative cycles might be required to perceive specific attributes of the target, such as its detailed shape or color. Simpler attributes, such as mere presence or absence, might require fewer cycles, in which case masking for these attributes would be reduced or eliminated.
- Metacontrast masking is known to diminish progressively with practice, until it disappears completely. This effect is a challenge for current theories of masking, because it suggests an adaptive tuning of attentional processes. Would the practice effect still occur if attention was distributed? Also, are the practice effects specific to the target and mask shapes used during practice or can they be generalized to include other stimuli?
- How do the unconscious processes that are devoted to a masked target (one that is never consciously experienced) differ from the processes that lead to conscious perception? Where in the brain are these types of processes dissociated?
- What other psychophysical effects provide a window for studying re-entrant cortical processes? The integration of signals in random dot motion displays appears to be one ready-made candidate, because the experience of coherent motion depends on intact communication between cortical areas V5 and V1 (Ref. 49). What are other psychophysical effects that should be examined for their suitability to this kind of analysis?
- Inhibitory theories of metacontrast regard masking by object substitution as the result of preceding inhibitory events. By contrast, the model described in this review regards object substitution itself as the cause of masking. What further studies would help to resolve this issue?

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